INITIAL RESULTS OF THE PINE LAKE RESTORATION PROGRAM

Alberta Environment

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SUMMARY

Pine Lake is a small eutrophic lake southeast of Red Deer, Alberta. Public concern over deteriorating water quality prompted the Alberta government to initiate a lake restoration program in 1991. The Pine Lake Restoration Program was intended as a pilot project for future lake and watershed projects in Alberta. An advisory committee that represented all stakeholders in the community directed early planning and problem diagnosis by technical advisors from the Alberta government. A diagnostic study in 1992 determined that approximately 61% of the total phosphorus (TP) loading was from sediment release and other internal sources, compared to about 36% from surface runoff, and determined that nuisance algal blooms in Pine Lake were mainly controlled by the supply of phosphorus.

The Pine Lake Restoration Society implemented a four-year work plan in 1995 that was designed to reduce phosphorus loading to streams in the watershed, and reduce internal loading from lake sediments. The watershed work plan consisted of various projects designed to reduce phosphorus loading from agricultural sites in or near four critical areas. Other community groups and individuals independently completed other projects that may also reduce nutrient loading, such as improved sewage disposal systems and projects at agricultural sites. To remove phosphorus released from lake sediments, a system designed to withdraw nutrient-rich water from the hypolimnion of Pine Lake was installed in 1998.

This report presents an evaluation of initial changes in water quality in Pine Lake following the completion of watershed projects (1995 - 1998), and during hypolimnetic withdrawal (1999, 2000). To evaluate the benefits and potential adverse impacts of hypolimnetic withdrawal, the report includes an evaluation of changes in water quality, lake level and thermal stratification in Pine Lake, and impacts on water quality in Ghostpine Creek, which receives the hypolimnetic discharge. The key water quality indicators that were evaluated in Pine Lake included changes in nutrient concentrations, in particular phosphorus and nitrogen, phytoplankton biomass (as chlorophyll *a*), and water transparency (as Secchi depth).

The Pine Lake Restoration Program demonstrates that communities can effectively plan and implement a watershed and lake stewardship program in partnership with government. The main objective of the restoration program was to restore Pine Lake to a "natural" level of algal productivity. Although median TP in Pine Lake in 2000 was above concentrations that may be indicative of natural conditions, algal biomass (as chlorophyll *a*) and transparency (as Secchi depth) approached levels thought to occur naturally. Sampling to date suggests that much of the improvement in water quality at Pine Lake can be attributed to the restoration program.

During hypolimnetic withdrawal, lake levels exceeded the preferred range for recreation and target lake levels for about two weeks in 1999 following unusually heavy rain. Levels were thereafter close to the acceptable range for recreation for the remainder of the season and for most of 2000.

Thermal stratification occurred in the middle and south basins each year, while the shallow north basin was sometimes nearly isothermal and partially mixed. Stratification influenced water temperatures in the hypolimnion, and probably influenced sediment phosphorus release some years. Stratification was moderately weak, and weather-induced mixing sometimes occurred. There was little evidence that hypolimnetic withdrawal adversely affected thermal stratification or caused premature mixing of the lake during the first two years of operation.

There was sufficient thermal stratification each summer that low levels of dissolved oxygen (< 1 mg/L) developed in the profundal waters of all three basins. Anoxic factors, which reflect the vertical extent and duration of anoxia, were greatest in 1995, 1997 and 1998. Although anoxia and sulphide levels in profundal waters have since declined, there has been little evidence to date that hypolimnetic withdrawal alone has reduced anoxia during the open water season. However, dissolved oxygen concentrations have improved during the winter since the completion of the restoration program in the middle basin of Pine Lake, perhaps due to declining oxygen demand.

Appreciable phosphorus release from lake sediments occurred nearly every summer in Pine Lake. This release was interrupted by weather-induced lake mixing in at least 1992 and 1999, and relatively little phosphorus release was detected by sampling in 1997.

Sediment core analysis at the University of Alberta suggested that Pine Lake was mesotrophic before European settlement in this watershed, which indicates a moderate level of algal productivity. In sampling by Alberta Environment, TP and chlorophyll *a* concentrations in the euphotic zone of Pine Lake increased significantly from levels just above the boundary between mesotrophic and eutrophic states in 1978 and 1979, to peak concentrations during 1992 to 1996. The reasons for this increase are not known.

TP concentrations in the three basins of Pine Lake declined significantly following the restoration program between 1996 and 2000 by 44 to 47%, and the mass of TP dropped by 25 to 32 %. Secchi depth has increased significantly, and the related variables turbidity and total suspended solids (as NFR) have greatly declined. The median concentration of chlorophyll *a* declined significantly by 76 to 81% in the three basins. However, nuisance algal blooms continued to occur during the late summer. Such algal blooms will likely continue to occur in Pine Lake during the late summer, but these blooms should decrease in severity and frequency if phosphorus levels continue to decline.

The biggest decline in TP mass in Pine Lake occurred during hypolimnetic withdrawal, and probably reflects the combined effects of increased phosphorus export during hypolimnetic withdrawal, decreased tributary loading, and export over the weir to Ghostpine Creek. The reduction in TP mass that can be attributed to each change cannot be estimated from the available data, but about 29% was due to hypolimnetic withdrawal. Water withdrawal by the Whispering Pines Golf and Country Club Resort also removed small amounts of phosphorus in 2000. Water withdrawal during the period of maximum internal loading would probably increase TP removal. However, water withdrawal by the resort must be coordinated with hypolimnetic withdrawal to maintain the target lake levels.

Although the flow from hypolimnetic withdrawal was less than the designed rate, 169 and 99 kg more total dissolved phosphorus (TDP) was exported to Ghostpine Creek during hypolimnetic withdrawal in 2000 than was exported in 1989 and 1992, respectively. The TDP mass removed by hypolimnetic withdrawal in 2000 was similar or greater than the TDP loading in 1992 from any of three Pine Lake tributaries that were significantly impacted by agricultural operations or sewage (Streams 1, 4, 6).

Flow from the hypolimnetic withdrawal system was about half that predicted in the project design report throughout 1999 and the latter part of the summer of 2000. Beaver dams that impounded the pipe outlet and reduced the effective head of the system, and floating of the pipe near the weir due to loss of weights probably caused reduced flows. The reasons that the pipe floated are not completely understood. Modifications to prevent floating of the pipeline were completed during the winter of 2001 - 2002.

Peak total nitrogen concentrations occurred in most basins of Pine Lake in 1992, and thereafter fluctuated at lower levels. Nitrogen concentrations did not decline to the same extent as phosphorus following the restoration program. During fall turnover, and weather-induced mixing events, ammonia levels in the surface waters of Pine Lake sometimes increased above the CCME water quality guideline following the movement of ammonia from the hypolimnion.

This analysis found little statistically significant variation between basins in the concentration of TP, chlorophyll *a*, or Secchi depth in the 15 years sampled during 1978 - 2000. Accordingly there is little evidence to date that one basin in the lake is more affected by the restoration program than the other basins. However, more spatial variation could occur in future during hypolimnetic withdrawal, which removes water from the southern basin.

Discharge from hypolimnetic withdrawal has: increased the concentration of some dissolved constituents; increased flow; and lowered water temperatures and dissolved oxygen just downstream from the point of discharge in Ghostpine Creek. However, results to date do not provide evidence of significant adverse impacts on water quality in Ghostpine Creek. Some floating algal mats were apparent in Ghostpine Creek near the outfall, but there was no historic data to assess changes in algal biomass. In spite of the increase in TDP concentration just downstream from the point of discharge, Ghostpine Creek remained relatively low in algal productivity. High turbidity may inhibit algal growth at sites on lower Ghostpine Creek.

Dissolved sulphide levels have declined in Pine Lake and in Ghostpine Creek downstream from the discharge of the hypolimnetic withdrawal since 1998. A further decline in sulphide concentration can be expected if dissolved oxygen levels in Pine Lake improve during the open water season. Such a decline would reduce the potential for odours associated with hypolimnetic discharge.

Factors such as differences in runoff between years, and natural variability, have probably contributed to improved water quality since 1996, and may account for unusually low levels of TP and chlorophyll *a* in 1995. Inflow volumes and maximum TP concentration were significantly correlated in Pine Lake. Accordingly, a temporary increase in phosphorus loading and phytoplankton biomass may occur in future during years with above average precipitation. However, there is no evidence to date of a widespread decline in TP concentration in other Alberta lakes since 1996, due to natural factors, that could adequately explain the decline in TP at Pine Lake. The concentration of TP declined in one lake less than half the decline in TP at Pine Lake, and chlorophyll *a* declined in two of nine Alberta reference lakes over the same time period.

Further monitoring will be required to conclusively demonstrate that improvements in water quality at Pine Lake are mainly due to the restoration program. The impact of watershed projects on nutrient loading to Pine Lake from tributaries should be assessed using a sampling program similar to the 1992 diagnostic study. Systematic records of weir heights and stop log operation, as recorded in 2000, are required for future assessments of phosphorus export from Pine Lake and will greatly assist future evaluations of weir operation. Benchmarks used to establish the staff gauges in Pine Lake should be periodically surveyed to ensure lake level elevations are correct.

TABLE OF CONTENTS

SUMMARY i
LIST OF TABLES vi
LIST OF FIGURES vii
LIST OF APPENDICES ix
ACKNOWLEDGEMENTS x
ABBREVIATIONS xi
1.0 INTRODUCTION 1
2.0 METHODS 8
  2.1 Sampling Methods and Analysis 8
  2.2 Data Analysis 9
3.0 RESULTS AND DISCUSSION 13
  3.1 Hydrology 13
    3.1.1 Annual Inflow Volumes 13
    3.1.2 Flow from the Hypolimnetic Withdrawal System 13
    3.1.3 Lake Level 16
  3.2 Physical, Chemical and Biological Characteristics of Pine Lake 16
    3.2.1 Water Temperature and Stratification 16
    3.2.2 Dissolved Oxygen and Sulphide 21
    3.2.3 Phosphorus 28
      3.2.3.1 Comparisons Among Lakes 33
      3.2.3.2 Comparisons Within Pine Lake 33
      3.2.3.3 Total Phosphorus Mass 35
    3.2.4 Nitrogen 39
    3.2.5 Phytoplankton Chlorophyll a 43
    3.2.6 Secchi Depth 52
    3.2.7 Major Ions 52
  3.3 Phosphorus Loading and Export from Pine Lake 56
  3.4 Response of Pine Lake to Reduced Phosphorus Loading 59
  3.5 Impacts of Hypolimnetic Withdrawal on Ghostpine Creek 60
4.0 CONCLUSIONS 69
  4.1 Restoration Program 69
  4.2 Physical, Chemical and Biological Characteristics of Pine Lake and Ghostpine Creek 69
5.0 LITERATURE CITED 72

LIST OF TABLES

Table 1 Lake and watershed projects completed at Pine Lake 3

Table 2 Specifications of the hypolimnetic withdrawal system at Pine Lake, Alberta 5

Table 3 Median open-water euphotic zone chlorophyll *a*, total phosphorus and Secchi depth in 10 lakes in Alberta provincial parks, 1982 to 2000. Trophic status is based on average levels of chlorophyll (OECD 1982) 10

Table 4 Significant monotonic trends in total phosphorus, chlorophyll *a*, and Secchi depth in the middle basin of Pine Lake and a reference lake (Gull Lake) 33

Table 5 Phosphorus (kg) export from Pine Lake before and during hypolimnetic withdrawal 58

LIST OF FIGURES

Figure 1 Lake, stream, and watershed project locations at Pine Lake 2

Figure 2a Water quality sampling sites on Ghostpine Creek 4

Figure 2b Conceptual cross-section of hypolimnetic withdrawal system installed in Pine Lake 6

Figure 3 Comparison of annual inflow volumes in Pine and Gull lakes 14

Figure 4 Measured and designed flow rate for the hypolimnetic pipeline, 1999 and 2000 15

Figure 5 Daily lake levels for Pine Lake during hypolimnetic pipeline operation 17

Figure 6 Historic daily lake levels for Pine Lake (05CE902) 18

Figure 7 Water temperature (°C) isopleths for Pine Lake south basin, open water season, 1992-2000 19

Figure 8 Water temperature (°C) isopleths for Pine Lake middle basin, open water season, 1992-2000 20

Figure 9 Water temperature (°C) isopleths for Pine Lake north basin, open water season, 1992-2000 22

Figure 10 Dissolved oxygen (mg/L) isopleths for Pine Lake south basin, open water season, 1992-2000 24

Figure 11 Dissolved oxygen (mg/L) isopleths for Pine Lake middle basin, open water season, 1992-2000 25

Figure 12 Dissolved oxygen (mg/L) isopleths for Pine Lake north basin, open water season, 1992-2000 26

Figure 13 Anoxic factors for Pine Lake during May to October, 1992-2000 27

Figure 14 Dissolved oxygen profiles (mg/L) under ice at three sites on Pine Lake during February 1978-2000 29

Figure 15 Euphotic zone composite total phosphorus (May-Oct) in Gull Lake and Pine Lake 30

Figure 16 Euphotic zone composite total phosphorus in the three basins of Pine Lake, 1992-2000 31

Figure 17 Total phosphorus mass in the three basins of Pine Lake, 1992-2000 32

Figure 18 Euphotic zone total phosphorus (May-Oct) in 10 provincial park lakes in Alberta 34

Figure 19 Total phosphorus (mg/L) isopleths for Pine Lake south basin, open water season, 1992-2000 36

Figure 20 Total phosphorus (mg/L) isopleths for Pine Lake middle basin, open water season, 1992-2000 37

Figure 21 Total phosphorus (mg/L) isopleths for Pine Lake north basin, open water season, 1992-2000 ... 38

Figure 22 Euphotic zone composite total dissolved phosphorus in the three basins of Pine Lake, 1992-2000 ... 40

Figure 23 Euphotic zone composite dissolved ortho phosphorus in the three basins of Pine Lake, 1992-2000 ... 41

Figure 24 Euphotic zone composite total nitrogen in the three basins of Pine Lake, 1992-2000 ... 42

Figure 25 Euphotic zone composite total kjeldahl nitrogen in the three basins of Pine Lake, 1992-2000 ... 44

Figure 26 Euphotic zone composite dissolved nitrite nitrogen in the three basins of Pine Lake, 1992-2000 ... 45

Figure 27 Euphotic zone composite dissolved nitrite+nitrate nitrogen in the three basins of Pine Lake, 1992-2000 ... 46

Figure 28 Euphotic zone composite dissolved ammonia nitrogen in the three basins of Pine Lake, 1992-2000 ... 47

Figure 29 Euphotic zone composite chlorophyll *a* (May-Oct) in Gull Lake and Pine Lake. 48

Figure 30 Euphotic zone composite chlorophyll *a* in the three basins of Pine Lake, 1992-2000 ... 49

Figure 31 Euphotic zone composite chlorophyll *a* (May-Oct) in 10 provincial park lakes in Alberta ... 50

Figure 32 Secchi depth (May-Oct) in Gull Lake and Pine Lake ... 53

Figure 33 Secchi depth in the three basins of Pine Lake, 1992-2000 ... 54

Figure 34 Euphotic zone Secchi depth (May-Oct) in 10 provincial park lakes in Alberta.... 55

Figure 35 Total phosphorus concentrations in Pine Lake streams, March to October, 1992 and 1996 ... 57

Figure 36 Concentration of total and dissolved phosphorus at three sites on Ghostpine Creek and in the hypolimnetic pipeline discharge ... 61

Figure 37 Concentration of nitrite+nitrate nitrogen and ammonia nitrogen at three sites on Ghostpine Creek and in the hypolimnetic pipe discharge ... 62

Figure 38 Concentration of chlorophyll *a* and dissolved oxygen at three sites on Ghostpine Creek and in the hypolimnetic pipe discharge ... 63

Figure 39 Concentration of dissolved sulphide in Pine Lake south basin and Ghostpine Creek at Range Road 245 ... 64

Figure 40 Water temperature in Ghostpine Creek near the Pine Lake outflow before (1989, 1992) and after (2000) the installation of the hypolimnetic withdrawal system... 65

Figure 41 Concentration of iron and aluminium at three sites on Ghostpine Creek ... 68

LIST OF APPENDICES

Appendix 1 Median values for samples collected during the open-water season from Pine Lake, 1992-2000 and Ghostpine Creek, 1986-2000

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Dave Trew provided invaluable guidance during the planning for this program, and with Sue Arrison worked extensively with the Advisory Committee and Restoration Society. Gord Ludtke, who designed the hypolimnetic withdrawal system as a consultant, continued to provide support in the analysis of results from this program. Dave Trew provided review comments on the draft report.

Ken Williamson and Neil MacAlpine of Alberta Agriculture, Food and Rural Development provided advice and worked to develop projects at farm sites designed to improve water quality in Pine Lake.

The Pine Lake Restoration Program was only possible because many volunteers donated long hours over many years for meetings, fundraising and worked on the various projects. I thank all members of the Advisory Committee, Pine Lake Restoration Society and the Pine Lake community for their strong commitment, hard work, and belief in the restoration program. In particular I thank members of the board and the Society presidents: Bill Wearmouth, Danny Fisher, and Doug Sawyer. Maurice Lewis and Penny Archibald represented the County of Red Deer on the Advisory Board, and remained strong supporters throughout the restoration program. I also thank the various farmers who agreed to work with the Society to complete watershed projects, in particular farmers that completed the first projects on their property and set an example for the community.

Gary Severtson, former Member of the Legislative Assembly for Alberta organized the Advisory Committee and continued to help the restoration program.

The Pine Lake Restoration Program was partially funded by the Pine Lake community through donations to the annual Clean Lake Day. Grants were also obtained from the Alberta Water Management and Erosion Control Program, the Community Facility Enhancement Program, the County of Red Deer, and the Canada-Alberta Environmentally Sustainable Agriculture and Alberta Environmentally Sustainable Agriculture programs.

ABBREVIATIONS

AENV	Alberta Environment
ASWQG	Alberta Surface Water Quality Guideline
BMP	Beneficial Management Practice
CCME	Canadian Council of Ministers of Environment
CEQG	Canadian Environmental Quality Guideline
dam^3	cubic decametres ($1\ dam^3 = 1000\ m^3$)
d/s	downstream
m	metres
mm	millimetres
m^3/s	cubic metres per second
µg/L	micrograms per litre
USEPA	United States Environmental Protection Agency
WSC	Water Survey of Canada

1.0 INTRODUCTION

Pine Lake is a small eutrophic lake southeast of Red Deer, Alberta. Pine Lake is subject to severe cyanobacterial blooms. Public concern over deteriorating water quality prompted the Alberta government to initiate a lake restoration program in 1991. The Pine Lake Restoration Program was designed as a pilot project for future lake and watershed projects in Alberta.

An advisory committee that represented all members of the community directed early planning and problem diagnosis by the Alberta government. A diagnostic study in 1992 (Sosiak and Trew 1996) determined that approximately 61% of the total phosphorus (TP) loading was from sediment release and other internal sources, compared to about 36% from surface runoff, and determined that algal growth in Pine Lake was mainly limited by the supply of phosphorus. Four critical areas for watershed restoration were identified on four streams affected by livestock operations and sewage release (Sosiak and Trew 1996). These streams contributed 72% of the phosphorus loading from streams in 1992.

The advisory committee later formed the Pine Lake Restoration Society, a non-profit organization with representatives from all stakeholders, which raised funds and worked with technical advisors from the Alberta government. The Pine Lake Restoration Society implemented a four-year work plan in 1995 that addressed phosphorus loading from all sources.

The main objective of the restoration program was to restore Pine Lake to a "natural" level of algal productivity. Sediment core analysis by Blakney (1998) determined that Pine Lake was mesotrophic before European settlement, a term that denotes an intermediate level of nutrients and algal production. A previous report (Mitchell and Sosiak 1991) suggested that water quality restoration might be possible if external phosphorus loading (from streams, atmospheric deposition, diffuse runoff) could be greatly reduced. Water quality modelling later determined that productivity near the border between mesotrophic and eutrophic conditions could be achieved if both external and internal phosphorus loading, primarily from lake sediments, could be greatly reduced (Sosiak 1997).

The watershed program initially consisted of various projects designed to reduce phosphorus loading to Pine Lake from agricultural sites. The Pine Lake Restoration Society and other individuals in the basin completed these projects, which consisted of beneficial management practices (BMPs) at various agricultural sites. Other organizations also improved wastewater treatment at a resort and two camps near the shoreline of Pine Lake. No work was planned along streams 2, 5, and 7 (Figure 1) of Pine Lake, as the phosphorus loading from these basins was relatively small in 1992 (Sosiak and Trew 1996). These basins serve as reference basins to evaluate the benefits of projects on the other basins. The watershed and projects completed at Pine Lake during 1995 to 1998 are summarised in Table 1, and approximate locations are marked on Figure 1 and 2.

Following an evaluation of the different alternatives to remove or treat phosphorus released from lake sediments, hypolimnetic withdrawal was selected as the preferred method of treatment. Hypolimnetic withdrawal has been successfully used to reduce TP concentration in various lakes,

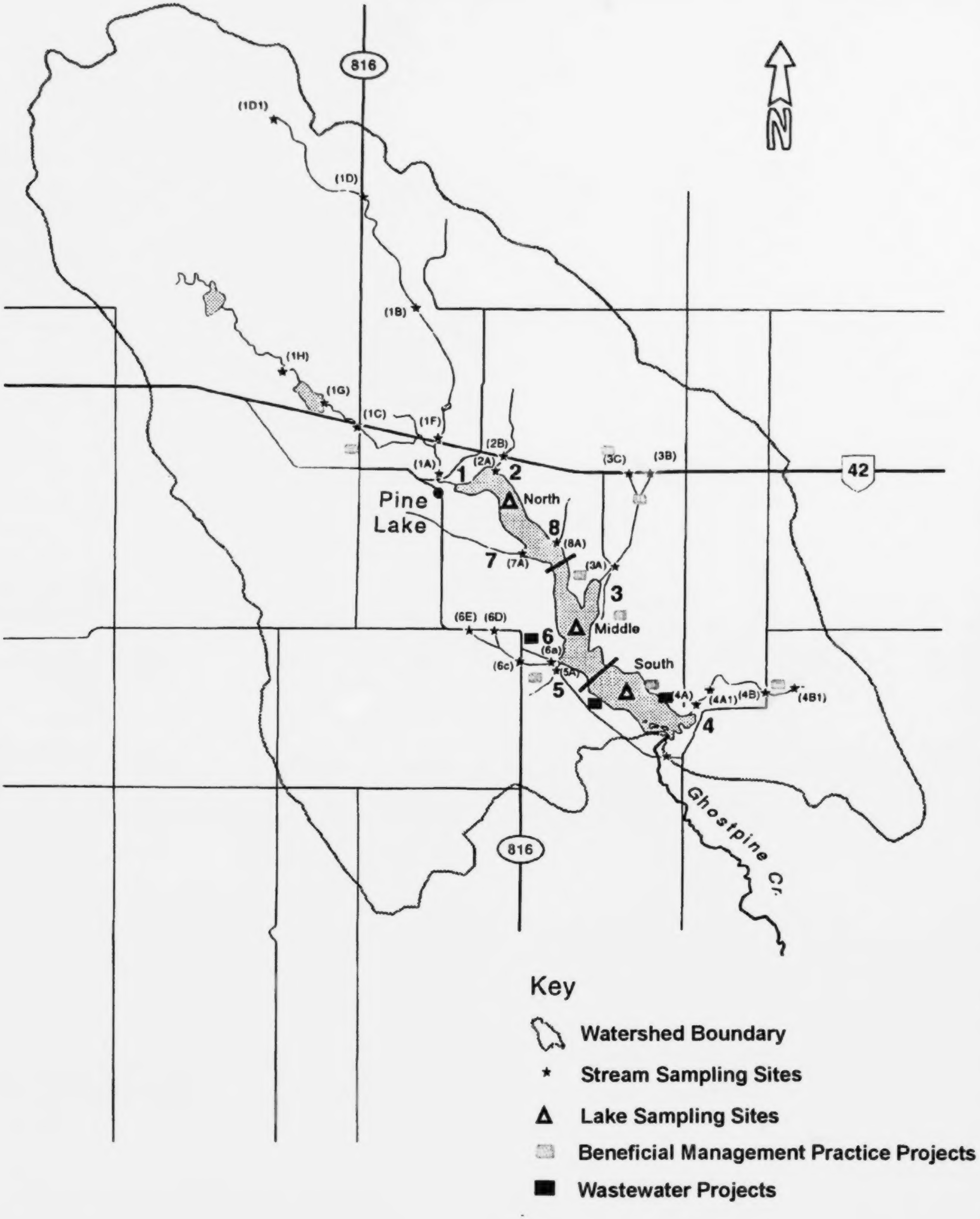
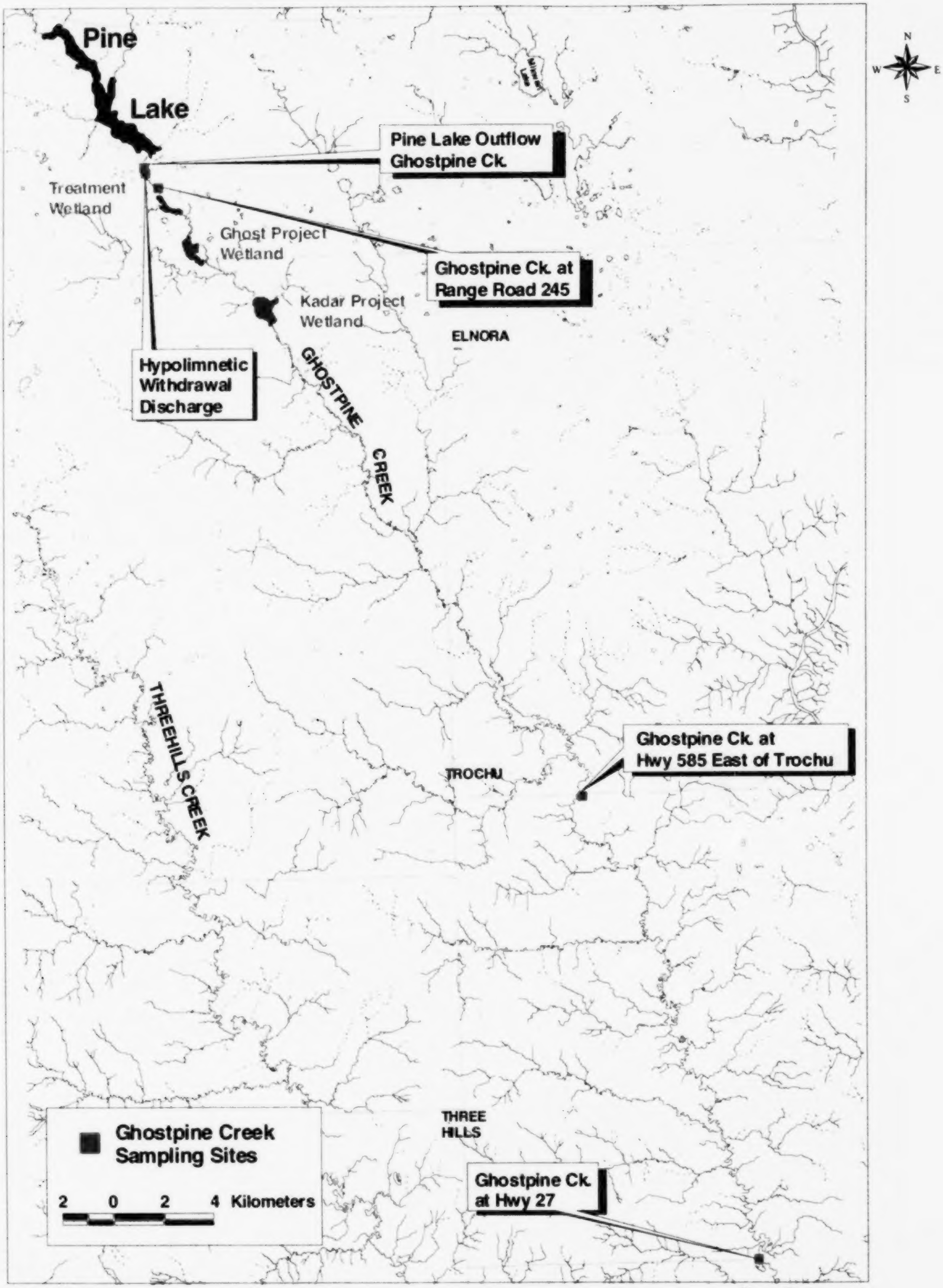

816
N
(1D1)
(1D)
(1B)
(1H)
(1G)
(1C)
(1F)
(2B)
(1A)
(2A)
1
2
(3C)
(3B)
42
Pine Lake
North
8
(8A)
7
(7A)
(3A)
3
Middle
(6E)
(6D)
6
(6a)
(6c)
(5A)
5
South
(4A)
(4A1)
(4B)
(4B1)
4
Ghostpine Cr.
816
Key
Watershed Boundary
Stream Sampling Sites
Lake Sampling Sites
Beneficial Management Practice Projects
Wastewater Projects

Figure 1 Lake, stream, and watershed project locations at Pine Lake

Table 1 Lake and watershed projects completed at Pine Lake

Year	Location	Proponent	Description of Watershed and Lake Projects
Watershed Projects at Farm Sites			
1993-94	East of Stream 3	Farmer	Two retention ponds installed to contain runoff from dairy barn and grazing area at dairy farm
1995	Stream 4	PLRS[a]	Diversion of upslope runoff and installation of containment pond at sheep farm
1995	Stream 6	PLRS	Hill graded (levelled in 1998) and road provided for new livestock wintering/feeding area on stream 6
1995	West of Stream 3	PLRS	Provided dugout for off-lake watering along eastern shoreline of lake
1996	Southeast Shoreline	Farmer	Cattle moved to new site from watering area along southeast shoreline
1996	Tributary of Stream 1	Farmer	Installed berm to contain runoff from wintering site on tributary
1997	Stream 3 Headwaters	PLRS	Grading and seeding of slope to divert runoff to catch basin, and provide livestock wintering and feeding area
1997-98	Stream 3	PLRS	Berm with spillway and control structure installed to create detention pond below critical area on stream 3
Sewage Treatment			
1993	Southwest Shore	Owner	Existing sewage lagoons replaced at Salvation Army Camp
1995	North of Stream 6	Owner	New sewage lagoons installed at Ghostpine Resort
1999	Southeast Shore	Owner	Major upgrade of existing septic field system at B'nai Brith Camp
In-lake Treatment			
1994	Lake Outlet	PLRS	Dredging of lake outlet to reduce risk of flooding and shoreline erosion
1998	South Basin, Outlet	PLRS	Installation of hypolimnetic withdrawal system
2000	Ghostpine Creek	PLRS	Berm and control structure installed to create a new wetland, completed in the fall of 2000

[a] Pine Lake Restoration Society


N
W
E
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Pine
Lake
Pine Lake Outflow
Ghostpine Ck.
Treatment
Wetland
Ghost Project
Wetland
Ghostpine Ck. at
Range Road 245
Kadar Project
Wetland
ELNORA
Hypolimnetic
Withdrawal
Discharge
GHOSTPINE
CREEK
THREEHILLS CREEK
TROCHU
Ghostpine Ck. at
Hwy 585 East of Trochu
THREE
HILLS
Ghostpine Creek
Sampling Sites
2 0 2 4 Kilometers
Ghostpine Ck.
at Hwy 27

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Figure 2a Water quality sampling sites on Ghostpine Creek

mainly in Europe (Nürnberg 1987), but has never been attempted in Alberta. Following a review of the diagnostic study report (Sosiak and Trew 1996), Gertrud Nürnberg recommended that this option should be considered for Pine Lake. Two different designs for the Pine Lake system were prepared and evaluated and, following public notice and licensing, the system was installed in September 1998.

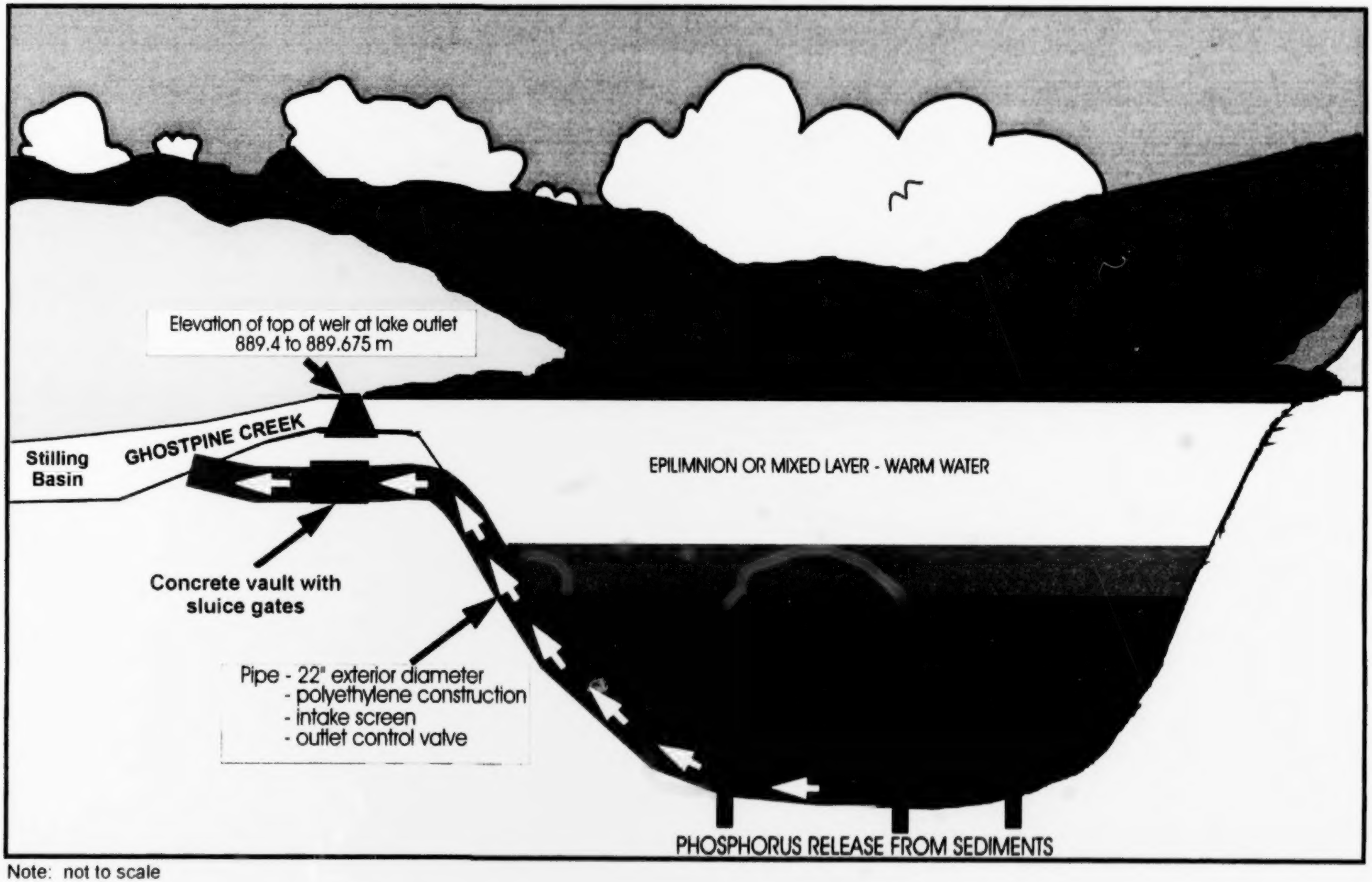
The system at Pine Lake consists of a weir that maintains head and regulates lake level, and a gravity-fed pipeline that withdraws cool, phosphorus-rich water from the hypolimnion of the south basin, and discharges through a control vault to a stilling basin on Ghostpine Creek (Figure 2b). Further details on this system are in Table 2, and the engineering report (AWARE Engineering Ltd. 1997). In the late fall of 2000, a wetland was created on Ghostpine Creek downstream from the system discharge, below Range Road 245 (Figure 2a). This wetland first filled during 2001. Along with the two existing wetlands on Ghostpine Creek (Figure 2a), this new wetland should remove nutrients from the hypolimnetic discharge.

Table 2 Specifications of the hypolimnetic withdrawal system at Pine Lake, Alberta

Variable	Dimension
Pipe Length, intake to control vault	1400 m
Pipe Internal Diameter, intake to control vault	530 mm
Pipe External Diameter, intake to control vault	~ 560 mm
Pipe External Diameter, control vault to stilling basin	610 mm
Pipe Material	High-density polyethylene (HDPE)
Intake Elevation (depth at lake level 889.675)	879.5 m (10.18 m depth)
Proposed Lake Level Range (Date) at Full Supply Level	≥ 889.675 (May 1) to 889.400 (Sept 7)
Range of Potential Discharge	0.0863 - 0.1254 m^3/s

This report presents an evaluation of initial changes in water quality in Pine Lake during the period that watershed projects were completed (1995 - 1998), and following the installation of the hypolimnetic withdrawal system in 1998 using data up to February 2001. To determine if water quality trends at Pine Lake could also be influenced by trends in climate and other natural factors, key water quality indicators in Pine Lake were compared to results from ten other lakes in various ecoregions throughout Alberta. Trends in key water quality indicators were evaluated statistically for Pine Lake and a eutrophic reference lake (Gull Lake) without major changes in lake or watershed management, also in Aspen Parkland

Hypolimnetic withdrawal has sometimes caused early destratification, and caused upward movement of nutrients from the hypolimnion of a lake and enhanced algal blooms. Other potential concerns reviewed in Nürnberg (1987) include odour caused by hydrogen sulphide.


Elevation of top of weir at lake outlet
889.4 to 889.675 m
GHOSTPINE CREEK
Stilling Basin
EPILIMNION OR MIXED LAYER - WARM WATER
Concrete vault with sluice gates
Pipe - 22" exterior diameter
- polyethylene construction
- intake screen
- outlet control valve
PHOSPHORUS RELEASE FROM SEDIMENTS

Note: not to scale

Figure 2b Conceptual cross-section of hypolimnetic withdrawal system installed in Pine Lake

toxic levels of ammonium and metals, and nutrient impacts in waters that receive the hypolimnetic discharge. Accordingly the assessment of Pine Lake results focused on changes in these variables in Ghostpine Creek, and changes in key water quality indicators, TP mass, dissolved oxygen, thermal stratification, pipeline flow, and lake level in Pine Lake during hypolimnetic withdrawal. The key indicators that were evaluated included changes in nutrient levels, in particular phosphorus and nitrogen, phytoplankton biomass (as chlorophyll *a*), and water transparency (as Secchi depth). To evaluate the success of the restoration program, these changes were compared to levels that were thought to have occurred naturally in Pine Lake.

The Whispering Pines Golf and Country Club Resort was licensed in 2000 to withdraw up to 68.2 dam^3/year from the middle basin of Pine Lake for golf course irrigation when lake level exceeds 889.475 m. To enhance phosphorus withdrawal, the resort installed their intake on the lake bottom about 11 m deep in 2000, and withdrew water under temporary authorizations in 1999 from about 3.7 m depth. This report also includes estimates of the amount of TP withdrawn in this irrigation water.

2.0 METHODS

2.1 Sampling Methods and Analysis

Locations of historic sampling sites and inflow tributary locations are in Figure 1. Sites sampled on Ghostpine Creek are in Figure 2a. All sampling followed field methods described in Alberta Environmental Protection (1993).

The lake was sampled at different intervals in the open water season during 1978 to 2000. Sampling was done at weekly intervals during the summer of 1992, fortnightly in the summers of 1993, 1999 and 2000, and once per month at other times, during the winter and in other years. Three sampling stations and sub-basin boundaries were established on the lake in 1978 (Figure 1), and were sampled consistently during 1978 - 2000. Three basins were sampled because the lake is long and narrow, with more inflows near the middle basin, and water quality was expected to differ from one end to the other.

Grab samples were collected in 1999 and 2000 once per month at two locations on lower Ghostpine Creek that were sampled prior to hypolimnetic withdrawal in 1986, and on Ghostpine Creek at Range Road 245, about 700 m downstream from the stilling basin (Figure 2a). Water temperature, dissolved oxygen, pH, and specific conductance were measured using Hydrolab meters when Ghostpine Creek sites were sampled, and a thermograph that records water temperature hourly was installed just downstream from the stilling basin and verified with a certified thermometer in 2000. The hypolimnetic withdrawal discharge was sampled fortnightly for nutrients in 2000. Flow was measured and temperature, dissolved oxygen, pH, and specific conductance were measured fortnightly in the pipeline discharge in both 1999 and 2000, with regular verification of dissolved oxygen by Winkler titration.

Winter samples were collected once per month at the deepest site in each basin, in both January and February 1993 to 1995, and thereafter only in February when the extent of anoxia was greatest. Samples were collected at mid-depth in winter for all variables except for phosphorus and chlorophyll *a*, which were also sampled just below the ice and within one metre of the lake bottom.

Depth profiles of temperature, dissolved oxygen, pH, specific conductance, and redox (after June 8, 1992) were measured at a one meter depth interval at the deepest site in each basin with Hydrolab meters (Hydrolab, Austin, Tx), with regular verification of dissolved oxygen by Winkler titration. Water samples were also collected at discrete two-metre intervals throughout the water column, except for the final three metres from the bottom, which were sampled at a one-meter interval. These samples from these profile sites were analyzed for various forms of nitrogen (ammonia, total kjeldahl nitrogen, nitrite+nitrate) and phosphorus (TP, TDP) in 1992, both forms of phosphorus to February 1997, but thereafter only TP.

To sample nutrients throughout the depth of light penetration (euphotic zone), and algal growth, vertically integrated, composite water samples were collected using a tube sampler starting in 1980, from 10 sites in each basin and pooled by basin for chemical analysis. The euphotic zone was defined as the interval between the surface and the depth of 1% of surface penetrating light. Light penetration was routinely measured with either a Protomatic (Protomatic, Dexter, MI) or a Li-Cor (Li-Cor Biosciences, Lincoln, NEB) underwater photometer. Early sampling did not include euphotic zone composites. In 1978 and 1979, discrete samples were collected from 1-m depth, the middle of the water column and 1 m above the bottom. Results from the 1-m depth in 1978 and 1979, before euphotic zone sampling began, were used in place of euphotic zone composite results in this analysis.

Euphotic zone composite samples from Pine Lake and ten reference lakes in provincial parks were analyzed for TP, TDP, and chlorophyll *a* concentration during 1984 to 2001 at the Monitoring Branch, Alberta Environment (AENV) laboratory in Edmonton. All other chemical analysis, duplicate composite samples for phosphorus, and phosphorus profile samples were done at the Alberta Research Council (formerly the Alberta Environmental Centre) laboratory in Vegreville, Alberta except for 1978, 1979 and 1996. In 1978 and 1979, samples were analysed at the Pollution Control Laboratory of AENV. During the open water season of 1996, and February 1997, Maxxam Analytics Inc. (formerly Chemex Labs Alberta Inc.) conducted analysis otherwise done at the Alberta Environmental Centre. Grab samples were collected from the surface at the profile sampling sites and analyzed for total and fecal coliform counts at the Provincial Health Laboratory for Southern Alberta in 1992 only.

2.2 Data Analysis

To permit numerical analysis, values less than detection limits were replaced by values one-half the detection limit. Data were then compared to the Alberta Surface Water Quality Guidelines (ASWQG), (AENV 1999), the Canadian Environmental Quality Guidelines (CEQG) (CCME 1999 and 2000), or United States Environmental Protection Agency Guidelines (USEPA 1986). Concentrations of undissociated hydrogen sulphide were calculated for the ambient pH, conductivity, and water temperature from dissolved sulphide measurements using the procedures in Greenberg et al. (1992), and compared to the USEPA guideline (2 µg/L) for this form of sulphide.

To evaluate changes in TP mass in Pine Lake over time, the mass in each basin for each sampling date was estimated from measured TP concentrations and volume estimates at all depth intervals. Surface interval volumes were adjusted to reflect the actual lake level on each sampling date. The peak TP mass estimates for each the three basins were added to provide an estimate of mass over the entire lake.

To determine if natural factors apart from management activities could account for water quality improvements at Pine Lake, trends in water quality at Pine Lake were compared to results from ten other lakes, in various ecoregions throughout Alberta sampled over a long period of time (11 - 19 years)(Table 3). All but Elkwater Lake are productive lakes, with trophic states ranging from eutrophic to hypereutrophic (Table 3). Trends were evaluated statistically for Pine Lake and a nearby reference lake (Gull Lake), also largely in the same Aspen Parkland ecoregion. Both lakes have similar land use (mixed farming and intensive recreation), and are eutrophic. However, Gull Lake was less productive than Pine Lake during 1992 - 1998, has a much longer

Table 3 Median open-water euphotic zone chlorophyll *a*, total phosphorus and Secchi depth in 10 lakes in Alberta provincial parks, 1982 to 2000. Trophic status is based on average levels of chlorophyll (OECD 1982).

	Trophic Status*	Chlorophyll (µg/L)	Total Phosphorus (µg/L)	Secchi Depth (m)	Median No. of Samples	Years of Data (Range)
Elkwater	M	4.8	36.6	2.0	5	19 (1982-2000)
Gregoire	**E**	**7.2**	**29.2**	**2.1**	**4**	**12 (1989-2000)**
Gull	E	8.3	46.3	2.3	4	16 (1983-2000)
Long (near Boyle)	**E**	**16.0**	**42.4**	**2.1**	**5**	**18 (1983-2000)**
McLeod East	E	6.9	23.7	3.1	5	17 (1984-2000)
North Buck	**E**	**6.9**	**29.2**	**2.0**	**4**	**11 (1986, 1991-2000)**
Saskatoon	HE	28.8	833.9	0.8	4	15 (1986-2000)
Steele	**HE**	**23.4**	**79.3**	**1.7**	**5**	**18 (1983-2000)**
Sturgeon Main	HE	15.9	73.6	2.3	4	18 (1983-2000)
Thunder	**HE**	**19.2**	**54.4**	**1.5**	**5**	**18 (1983-2000)****

*Trophic Status:
O = Oligotrophic (average summer chlorophyll *a* less than 2.5 µg/L)
M = Mesotrophic (average summer chlorophyll *a* between 2.5 and 8 µg/L)
E = Eutrophic (average summer chlorophyll *a* between 8 and 25 µg/L)
HE = Hypereutrophic (average summer chlorophyll *a* greater than 25 µg/L)
** Includes data from other sampling programs

residence time and has not discharged for many years. Gull Lake also has a much smaller ratio of watershed to lake area (2.6) than Pine Lake (37.8), which means that water quality in Pine Lake should be more influenced by watershed activities.

To evaluate whether apparent differences between basins and trends in concentration over time were statistically significant, or merely random variation, the euphotic zone concentration of TP, chlorophyll *a*, and Secchi depth during the open water season were evaluated statistically. Differences in median concentration among basins were tested using a Kruskal-Wallis one-way analysis of variance ($\alpha = 0.10$), followed by an Experimentwise Kruskal-Wallis Multiple Comparison Test.

To statistically evaluate trends in concentration before (up to 1995) and after the Pine Lake Restoration Program (1996-2000), data from Pine Lake and Gull Lake were tested for monotonic trends (gradual increasing or decreasing concentration). Data collected during 1996 - 2000 were grouped for analysis because construction of the first major watershed project began during the spring of 1995. Since the bulk of inflow to Pine Lake typically occurs in March to May (Sosiak and Trew 1996), it was assumed that any significant impacts of watershed projects on nutrient loading from surface runoff would occur during the spring of 1996. Catch basins were installed

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Variables were first tested with the Kruskal-Wallis test for seasonality. Variables exhibiting significant seasonality were tested for monotonic trends using the Seasonal Kendall Test, with (SKWC) or without (SKWOC) correction for significant serial correlation using procedures in the computer program WQHYDRO (Aroner 2000). The SKWOC test was used for the time period 1996-2000, as less than 10 years were available (Hirsch and Slack 1984, cited in Aroner 2000). Data that did not display significant seasonal variation were tested for monotonic trends using the Mann-Kendall test. Intermediate trend statistics were calculated for monthly median values, except where less than 10 years of data were available, in which case quarterly statistics were calculated (Aroner 2000), then intermediate statistics were combined in an annual trend statistic. As recommended by Ward et al. (1990), a 0.10 level of statistical significance was used to assess the results of all trend tests. Sen slopes were calculated to provide an estimate of the approximate magnitude of significant monotonic trends.

To evaluate whether changes in precipitation could account for changes in water quality over time in Pine Lake and a reference lake (Gull Lake), the relationship between water quality and annual runoff volume was evaluated statistically. This work was designed to test the hypothesis that higher nutrient loading to these lakes, and higher euphotic zone concentration, occur during years with higher runoff. There are no long-term flow gauging stations in the watershed of either lake. The Hydrology Section, Water Sciences Branch, AENV provided estimates of weekly, monthly and annual inflow volumes to Pine Lake and Gull Lake. Flows from representative gauges near each watershed (Pine Lake: WSC Station 05CE018, Threehills Creek below Ray Creek, Gull Lake: WSC Station 05CC001, Blindman River near Blackfalds) were adjusted to reflect the drainage areas of each lake. Spearman Rho Rank Correlation was used to determine whether median and maximum TP and chorophyll *a* concentration, and Secchi depth, were significantly ($\alpha = 0.10$) correlated with estimated annual inflow, spring inflow (March - June), and annual inflow during the previous year.

To determine whether the stated goal of the restoration program had been achieved, the median concentration of TP and chorophyll *a*, and Secchi depths, were compared to boundary values thought to be indicative of a "natural" level of productivity. "Natural" productivity was defined as the level of these variables that occurred prior to European settlement. Changes in productivity in Pine Lake over time were determined at the University of Alberta, through a study of diatom assemblages in sediment cores. Blakney (1998) concluded that Pine Lake was mesotrophic prior to European settlement until about 1972, after which it became increasingly eutrophic. Accordingly, the OECD fixed boundaries between mesotrophic and eutrophic categories (OECD 1982) were used to evaluate whether TP, chlorophyll *a*, and Secchi depth were typical of natural levels in Pine Lake after the completion of the restoration program. This approach assumes that algal productivity was naturally at the upper end of the mesotrophic range.

Blakney (1998) did not determine the position of Pine Lake within the mesotrophic range of productivity.

TP export to Ghostpine Creek from the hypolimnetic withdrawal in 2000 was estimated from flow measurements and TP and TDP measurements in the pipeline discharge. TP and TDP were not measured in the pipeline discharge in 1999. Accordingly, TP concentration at the deepest profile site in the south basin was used to prepare a TP export estimate for 1999, and TDP concentration at the same location was estimated using a regression equation ($TDP = -0.05435 + 1.35904(TP)+0.99193(TP)^2$, $N = 39$, $R^2 = 0.959$). Flow over the weir in 2000 was estimated by AWARE Engineering Ltd. (G. Ludtke) based on a stage-discharge relationship for the Pine Lake weir.

TP withdrawal from Pine Lake by the Whispering Pines Golf and Country Club Resort was estimated using the monthly average TP concentration measured in the middle basin at four and 11 m depth in 1999 and 2000 respectively, during water withdrawal. The General Manager of the resort provided volumes of water withdrawn by month each year.

The surface elevation of Pine Lake during hypolimnetic withdrawal was compared to the proposed schedule of lake levels in AWARE Engineering Ltd. (p. 12)(1997) here described as target levels. This schedule was intended to maintain lake levels within a range designed to optimise phosphorus withdrawal from the hypolimnion (889.400 - 889.675), but close to the range that AENV (1987) concluded was the desirable full supply level for Pine Lake (889.5 - 889.7). This recommendation was based on a survey of lake users, and was described as a compromise level designed to minimize impacts overall on various uses, including recreation, flooding, erosion, and man-made structures on the lake. Except for a maximum weir elevation of 889.675, no operational requirements for lake level were specified in the Interim License (No. 20880) to construct and operate the hypolimnetic withdrawal system. However, the license specified that the works were to be built according to specifications of the engineering report, which included recommended target lake levels.

Anoxic factors were prepared each year for each basin, following methods in Nürnberg (1995), and were used to graphically summarize the duration and vertical extent of hypolimnetic anoxia, here defined as dissolved oxygen < 1.0 mg/L. Because anoxic factors are corrected for lake surface area, they can also be used to compare anoxia in lakes of different sizes. Anoxia was assumed to end at each depth at fall turnover, the date of which was estimated using the procedure in Nürnberg (1988).

3.0 RESULTS AND DISCUSSION

Changes in physical, chemical, and biological variables (chlorophyll *a*) in Pine Lake and Ghostpine Creek are discussed in the following sections. Median concentrations for other water quality variables not discussed in detail are summarized in Appendix I.

3.1 Hydrology

3.1.1 Annual Inflow Volumes

Annual inflow estimates suggest there were more wet years in the Pine Lake area during the 1990's than during 1978 to 1989 (Figure 3). During 1990 - 2000, annual inflow volumes exceeded the long-term average (1971 - 2000: 2902 dam^3) (1 $dam^3 = 1000\ m^3$) in six years (54.5%), while annual inflow volumes were above average in just one year during 1978 - 1989 (8.3%)(annual inflow volumes in Figure 3), a period that included drought in the 1980's. During 1996 - 2000, inflows to Pine Lake were highly variable, with annual inflow volumes exceeding the 75th percentile (3865 dam^3) in three years and relatively dry (<25 percentile of 1042 dam^3) in the remaining two years (Figure 3).

In contrast to the inflow pattern at Pine Lake, annual inflow volumes were not as low at Gull Lake during 1978 – 1989, and high flows occurred with similar frequency at Gull and Pine Lake during 1990 - 2000. Annual inflow volumes to Gull Lake were above average in five years (38.5%) during 1978 - 1989, and in six years (54.5%) during 1990 - 2000 (Figure 3).

3.1.2 Flow from the Hypolimnetic Withdrawal System

Flow from the outlet of the hypolimnetic withdrawal system was only about half the design flow rate (AWARE Engineering 1997) in 1999 (Figure 4). Two factors probably caused these lower flow rates. Beavers began to rebuild dams in Ghostpine Creek that were removed during system installation, and raised the water level in the stilling basin. This increase in pond elevation at the outlet probably reduced the effective head. Dams were again removed and an ongoing beaver management program was implemented. Furthermore, a section of pipeline near the weir began to float late in the summer of 1999. Although the pipeline remained partly submerged and flow continued, resistance to flow was probably increased. Additional weights were applied to the pipeline and the floating section was buried later in 1999. Flows exceeded the flow rates predicted by AWARE Engineering until at least June 28, 2000, then declined during the summer. About 100 m of pipeline near the weir was again found floating late in 2001.

The reasons that this section of pipeline floated are not completely understood. The pipeline consists of high-density polyethylene that must be weighted to submerge the pipe. Stainless steel straps that held the weights in place had broken in the section that was floating. Expansion of the pipeline against tight straps probably caused this breakage (G. Ludtke, 2001. Personal communication). Gas accumulation at the highest elevation could also have made the pipe more buoyant. The change in water pressure as water is withdrawn from the hypolimnion may allow gases from photosynthesis and decomposition to leave solution and accumulate in the pipeline

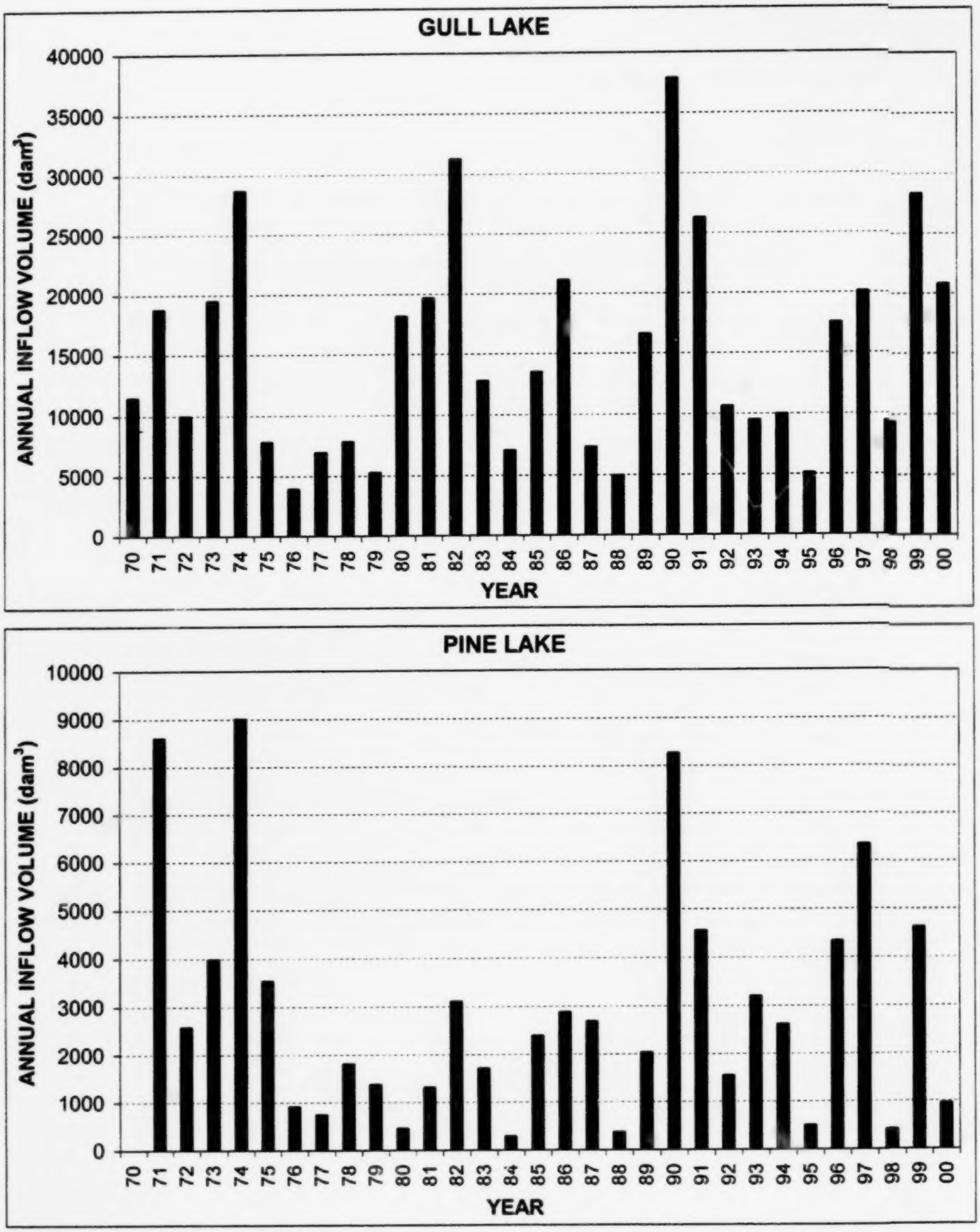


Figure 3 Comparison of annual inflow volumes in Pine and Gull lakes

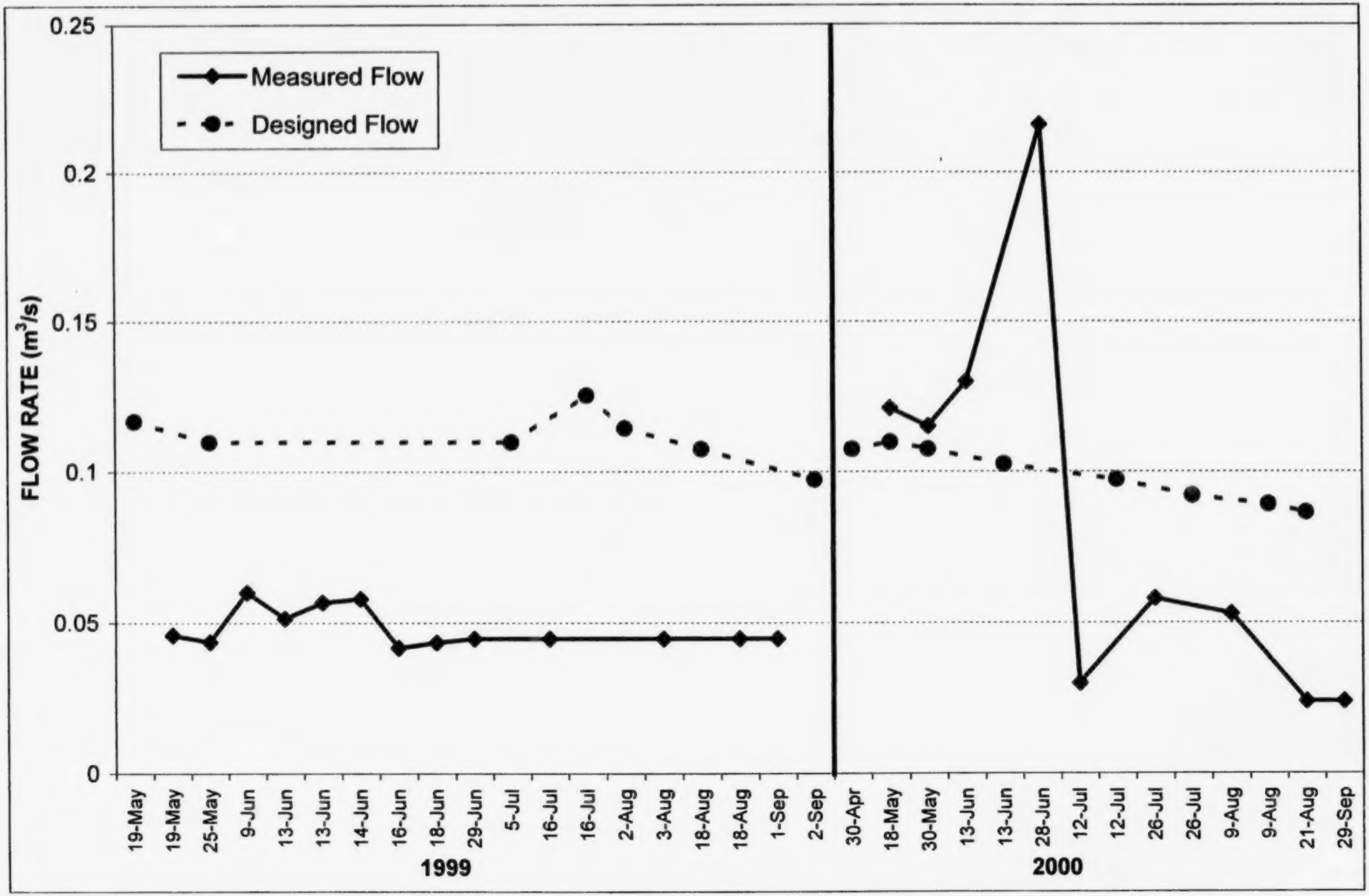


Figure 4 Measured and designed flow rate for the hypolimnetic pipeline, 1999 and 2000

over the summer at the highest elevation. Air entrainment would cause the pipeline to be more buoyant than was assumed when weights were designed for the system. Much heavier weights were added and modifications to allow the venting of any gas were completed during the winter of 2001 - 2002. These modifications consisted of two narrow diameter plastic pipes each attached to the top of the pipeline at the highest elevation, and each extending to the water surface.

3.1.3 Lake Level

Lake levels were higher than the target levels proposed by AWARE Engineering (1997) (Figure 5) for much of 1999. A period of unusually heavy rain raised lake levels 0.32 m between July 5 and July 19, 1999. Lake levels were still below the highest water levels that have been recorded historically, which occurred in 1990 (Figure 6). Stop logs were removed from the weir for much of the summer of 1999. However, the weir operator was unable to lower the lake level to the proposed target levels that operating season. Although lake levels exceeded the preferred range for recreation (AENV 1987) for at least 14 days in 1999, levels were thereafter within this preferred range for the remainder of the 1999-operating season.

In spite of the lack of runoff, lake levels were generally maintained within the preferred range for recreation and the proposed operating levels in 2000. Lake levels were initially below target levels early in 2000, probably because runoff was well below average that year (Figure 5). However, after June 26, 2000 levels were close to target levels for the remainder of the summer. Lake level fell 0.053 m below the recommended target level of 889.400 for the end of operations by September 13, 2000.

3.2 Physical, Chemical and Biological Characteristics of Pine Lake

3.2.1 Water Temperature and Stratification

Water temperature and thermal density stratification are important regulators of nearly all physical and chemical processes in a lake (Wetzel, 1983). Furthermore, impacts on stratification are a concern for hypolimnetic withdrawal, because premature mixing of the water column and massive algal blooms have been documented elsewhere during similar projects (Olszewski 1973, cited in Nürnberg 1987). Therefore, it is important to evaluate changes in temperature and stratification that have occurred over time in Pine Lake.

Some thermal stratification occurred in the middle and south basins each year (Figure 7 and 8), and strongly influenced water temperatures in the hypolimnion. Surface water temperatures were highest in all three basins in 1997 and 1998. Stratification was especially stable in the middle and south basins in 1997, and resulted in cooler temperatures than in other years in the bottom layer in the middle and south basins, at most 13.53°C in the south basin on September 23, 1997. The maximum difference between surface and bottom temperature was 13.2°C on August 6, 1997.

In contrast, the maximum difference between surface and bottom temperature in these two basins was only 3.9°C on July 31 during 1996, a year with lower water temperatures and less

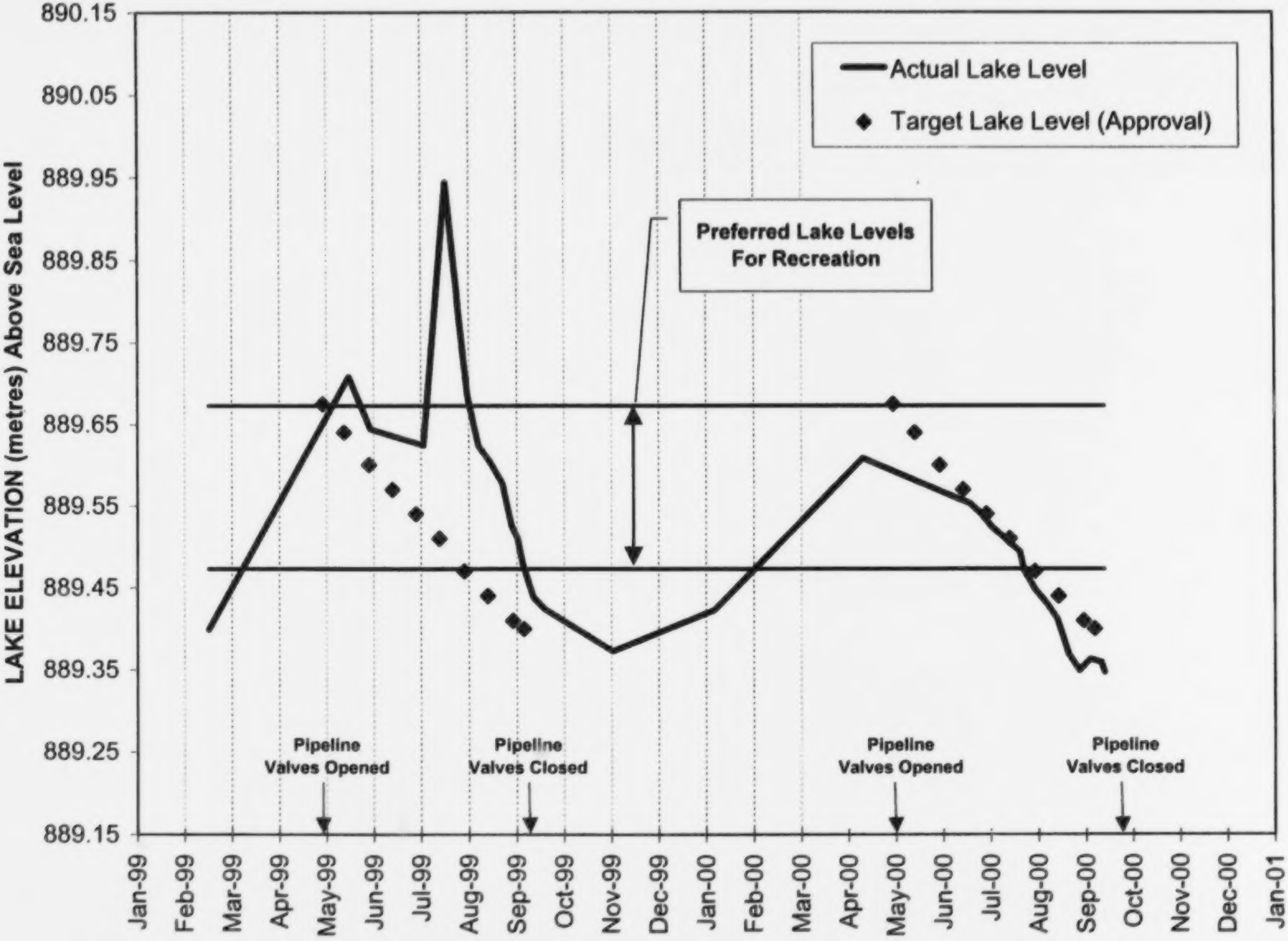


Figure 5 Daily lake levels for Pine Lake during hypolimnetic pipeline operation

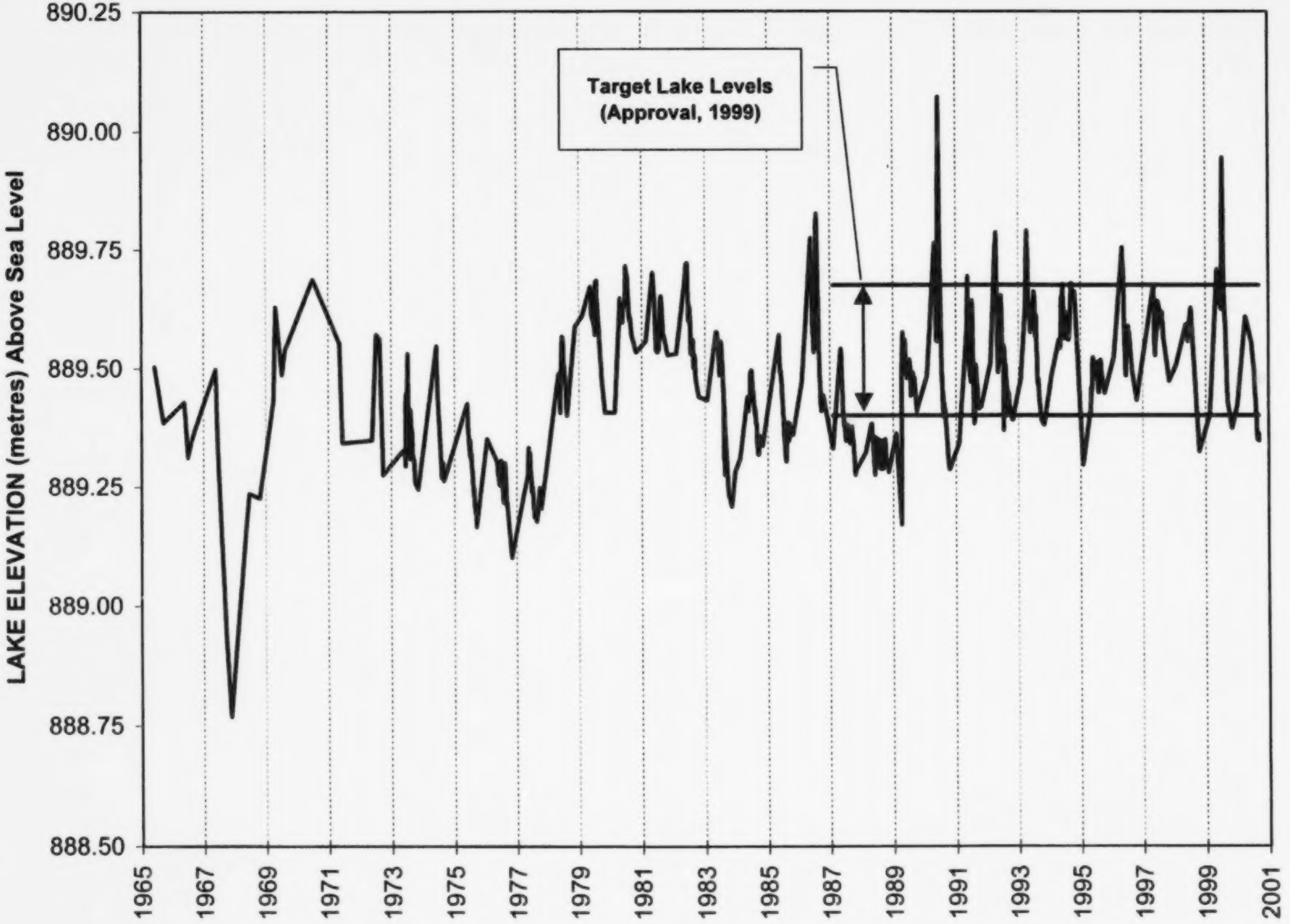


Figure 6 Historic daily lake levels for Pine Lake (05CE902)

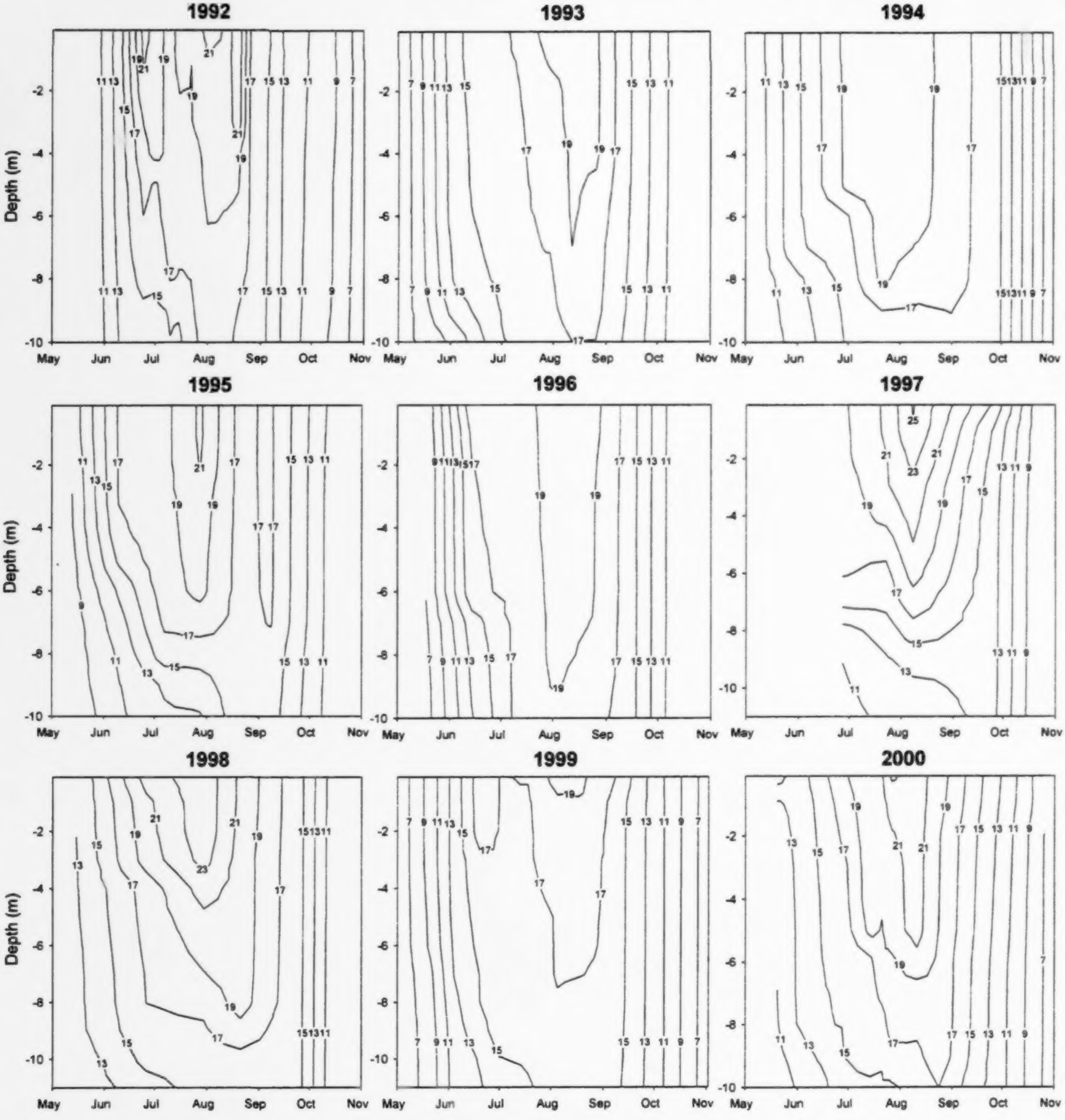


Figure 7 Water temperature (°C) isopleths for Pine Lake south basin, open water season, 1992-2000

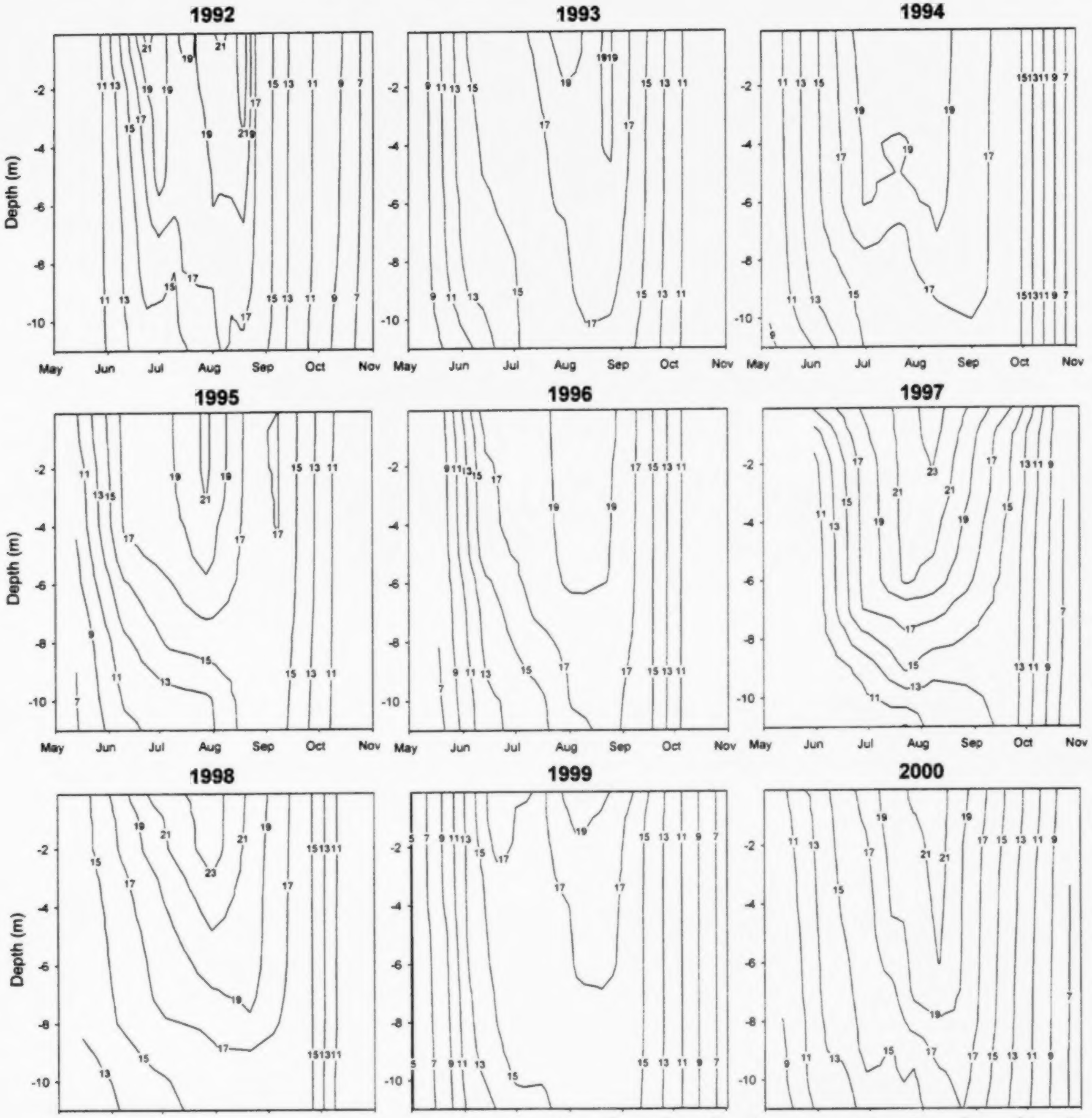


Figure 8 **Water temperature (°C) isopleths for Pine Lake middle basin, open water season, 1992-2000**

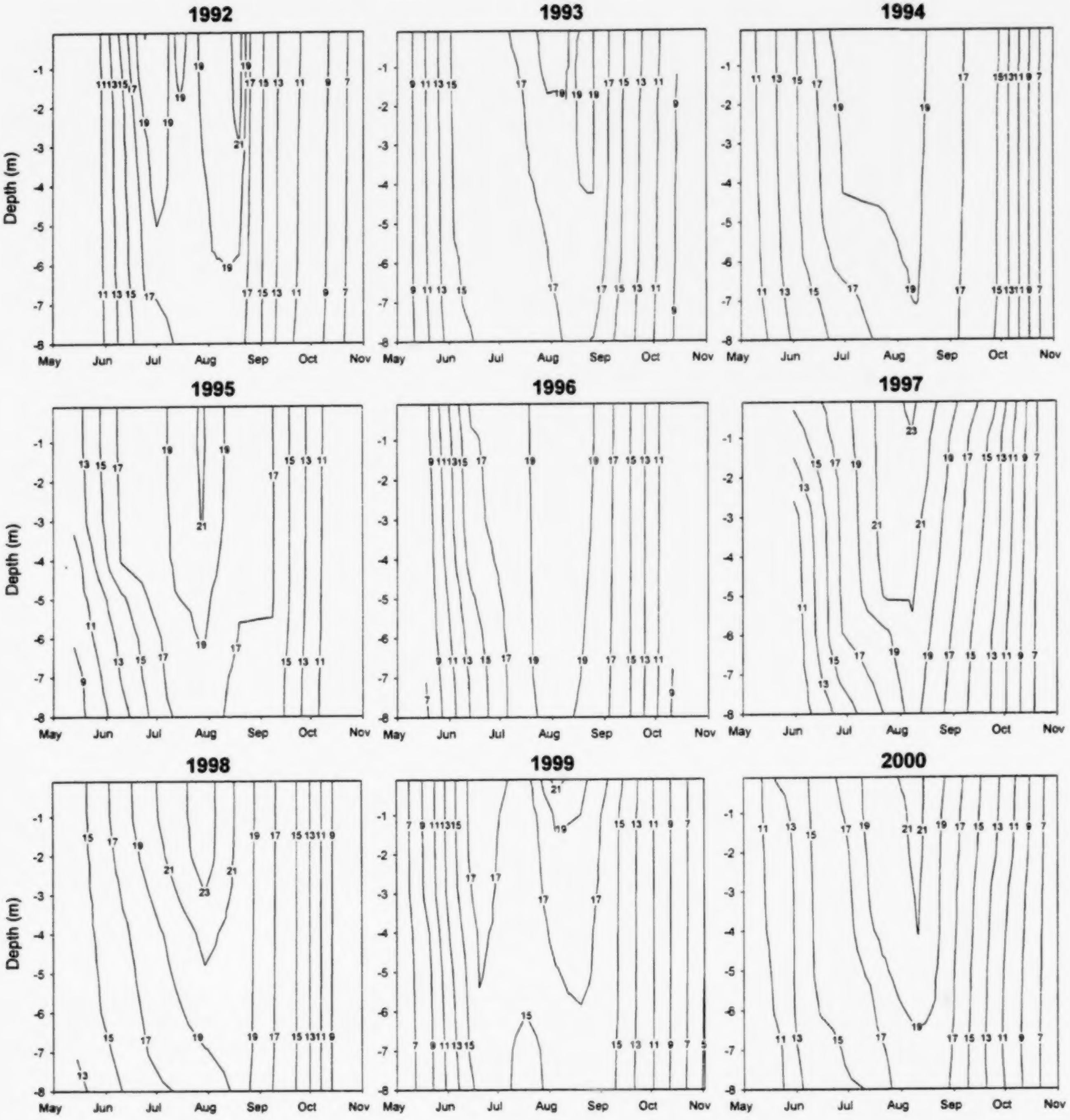
stratification than 1997. However, bottom temperatures exceeded 17°C in the middle and south basins in 1996 and 1992, and exceeded this temperature every year but 1999 in the north basin (Figure 9). Marsden (1989) concluded that sediment phosphorus release would occur above 17 - 21°C regardless of dissolved oxygen concentration, which also influences the rate of sediment phosphorus release. These warm temperatures in the hypolimnion probably increased the rate of sediment oxygen depletion, increased the rate of sediment phosphorus release in Pine Lake during 1992 and 1996, and allowed phosphorus release most years in the north basin even when the hypolimnion was largely oxic. Surface water temperatures were coolest in all three basins in 1993, 1994 and 1999.

Thermal stratification was moderately weak in all three basins. The shallow north basin remained nearly isothermal and weakly stratified during the summers of 1992, 1993, 1994, 1996, and 1999 (Figure 9). Two different weather events caused complete mixing of the lake in 1992, and partial mixing in 1999. An unusual summer snowstorm, followed by frost, occurred about August 24, 1992 and resulted in vertical mixing of the water column that summer (Sosiak and Trew 1996). In 1999, very heavy rainfall increased lake level by 0.32 m between July 5 and 19, and caused partial mixing of at least the north basin. The dissolved oxygen isopleths (Section 3.2.2) illustrate these mixing events.

There was little evidence that hypolimnetic withdrawal alone adversely affected thermal stratification and caused premature mixing of the water column during the first two years of operation. Normal stratification developed during hypolimnetic withdrawal in 2000, and prior to July 5, 1999, after which heavy rainfall occurred. Stratification began to develop again in all three basins later in the summer of 1999 during continued hypolimnetic withdrawal. As in years before hypolimnetic withdrawal, thermal stratification in Pine Lake remains weak and prone to instability due to unusual weather events. However, the available data suggest that hypolimnetic withdrawal has not adversely affected thermal stratification in Pine Lake. Even a rare weather phenomenon such as the tornado that crossed Pine Lake near the boundary between the north and middle basins (Figure 1) on July 14, 2000 appears to have had no lasting impact on thermal stratification during hypolimnetic withdrawal. All three basins were stratified on July 19, 2000.

3.2.2 Dissolved Oxygen and Sulphide

Adequate levels of dissolved oxygen are essential for the survival of fish and other aquatic organisms. Furthermore, oxygen distribution affects the solubility and availability of many nutrients, and therefore the productivity of aquatic ecosystems (Wetzel 1983). Hydrogen sulphide is typically formed by bacterial reduction of sulphate under anaerobic conditions in the hypolimnion of a stratified lake. Sulphide is relatively common in Alberta lakes with low levels of dissolved oxygen in bottom waters. When sulphide is dissolved in water, it forms hydrosulphide (HS^-) and toxic hydrogen sulphide (H_2S). The proportion of hydrogen sulphide depends on ambient pH, temperature and conductivity, and is lower in alkaline water (about 1% at pH = 9, USEPA 1986). Dissolved sulphide was measured in this study. Sulphide is potentially toxic to aquatic organisms, and may cause odours at low concentrations in water discharged from a hypolimnetic withdrawal. The duration and vertical extent of hypolimnetic anoxia (< 1.0 mg/L)



1992

1993

1994

1995

1996

1997

1998

1999

2000

Figure 9 **Water temperature (°C) isopleths for Pine Lake north basin, open water season, 1992-2000**

may be determined using anoxic factors (Nürnberg 1995). Anoxic factors represent the number of days in a year or season that a sediment area equal to the lake surface area is anoxic.

Although Pine Lake was weakly stratified and prone to mixing, there was sufficient thermal stratification each summer that near anoxia (< 1 mg/L) developed in the profundal waters of all three basins (Figures 10 to 12). The vertical extent and duration of anoxia was lower in the north basin than in the other two basins, as would be expected given the weak stratification of that basin. The extent and duration of anoxia was greatest in 1995, 1997 and 1998. Anoxic factors were similarly highest in these three years (Figure 13), but were generally below the range typical of eutrophic (40-60 d/summer) and hypereutrophic lakes (> 60 d/summer)(Nürnberg 1996).

Relatively weak stratification and early fall turnover probably caused lower anoxic factors in Pine Lake than are typical of productive lakes. The date of fall turnover was always predicted to occur by mid-September in Pine Lake during 1992-2000 (number of dissolved oxygen profiles: 6 – 18). Anoxic factors and the extent and duration of anoxia were lower than in the other years in 1993, 1996, 1999 and 2000.

The amount of anoxia that occurred each summer was probably influenced by the degree of thermal stratification. Anoxia was greatest in two warm years with stable thermal stratification, namely 1997 ($N = 6$) and 1998 ($N = 6$). Similarly, less anoxia occurred in years when complete or partial destratification occurred (1992, 1999) and during cooler years when the lake was weakly stratified (1993, 1996). Another important factor that would influence the amount of anoxia is the oxygen demand created by the decomposition of phytoplankton biomass produced each year, or the previous year. As will be discussed in Section 3.2.5, phytoplankton chlorophyll *a* was much lower in 1999 ($N = 11$) and 2000 ($N = 12$), than in the preceding years. Similarly, chlorophyll *a* was unusually low in 1995, and anoxic factors were low in 1996.

During 1996 - 2000, dissolved sulphide levels were highest in samples collected from the bottom of the south basin during years with prolonged anoxia in the hypolimnion waters, namely 1997 and 1998 (Figures 10 to 12). All hydrogen sulphide measurements from the hypolimnion of the south basin during June to August 1997 and 1998 were over the USEPA guideline for the protection of aquatic life (Figure 39 in Section 3.5). Since 1998, dissolved sulphide levels have declined as dissolved oxygen levels increased in the hypolimnion of this basin.

There has been little evidence to date that withdrawing anoxic water from the south basin of Pine Lake has by itself reduced the extent or duration of anoxia during the open water season. The anoxic factor in the south basin in 2000 (16.4 days/season) was similar or greater than estimates for this basin for 1992 - 1996 (4.6 - 18.2 days/season), before hypolimnetic withdrawal (Figure 13). A reduction in anoxia during the open water season may occur if phytoplankton biomass continues to decline in Pine Lake. Nürnberg (1987) noted that the duration of anoxia during summer stratification has decreased in seven lakes with hypolimnetic withdrawal systems, but did not decrease in two other lakes.

In contrast to the open water season, dissolved oxygen concentrations appear to have improved since 1998 during the winter in the middle basin of Pine Lake. Dissolved oxygen has been

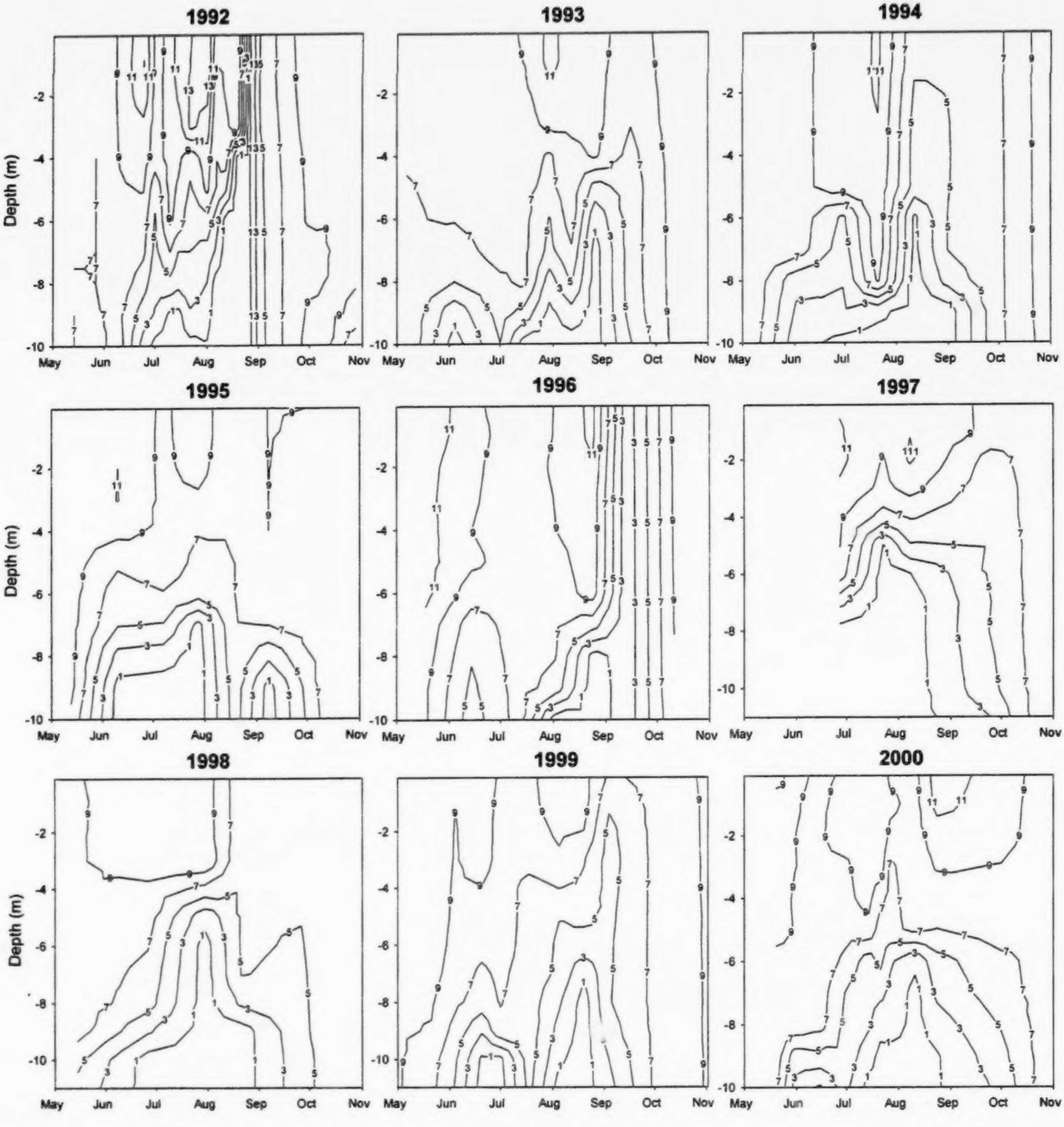


Figure 10 Dissolved oxygen (mg/L) isopleths for Pine Lake south basin, open water season, 1992-2000

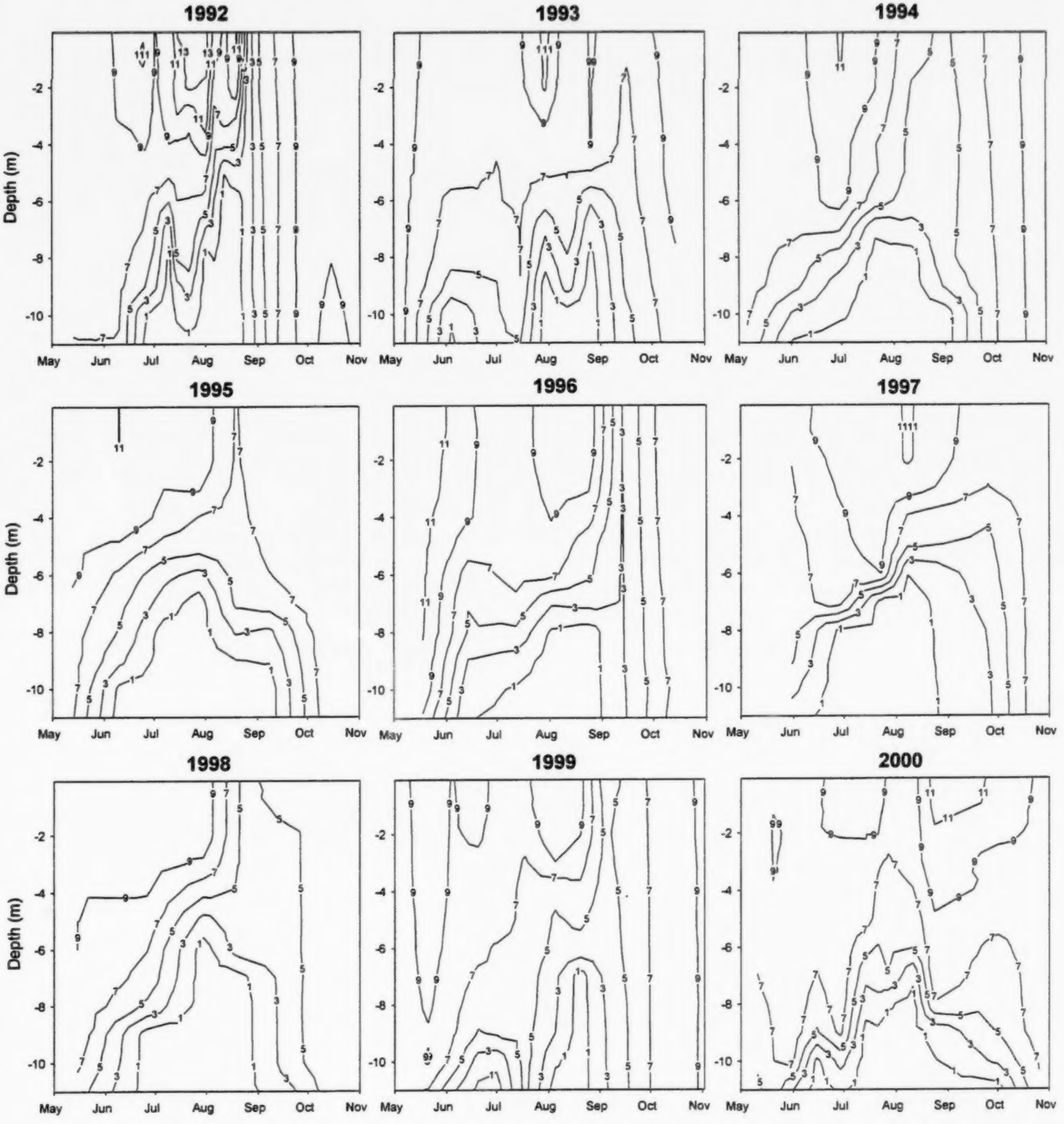


Figure 11 Dissolved oxygen (mg/L) isopleths for Pine Lake middle basin, open water season, 1992-2000

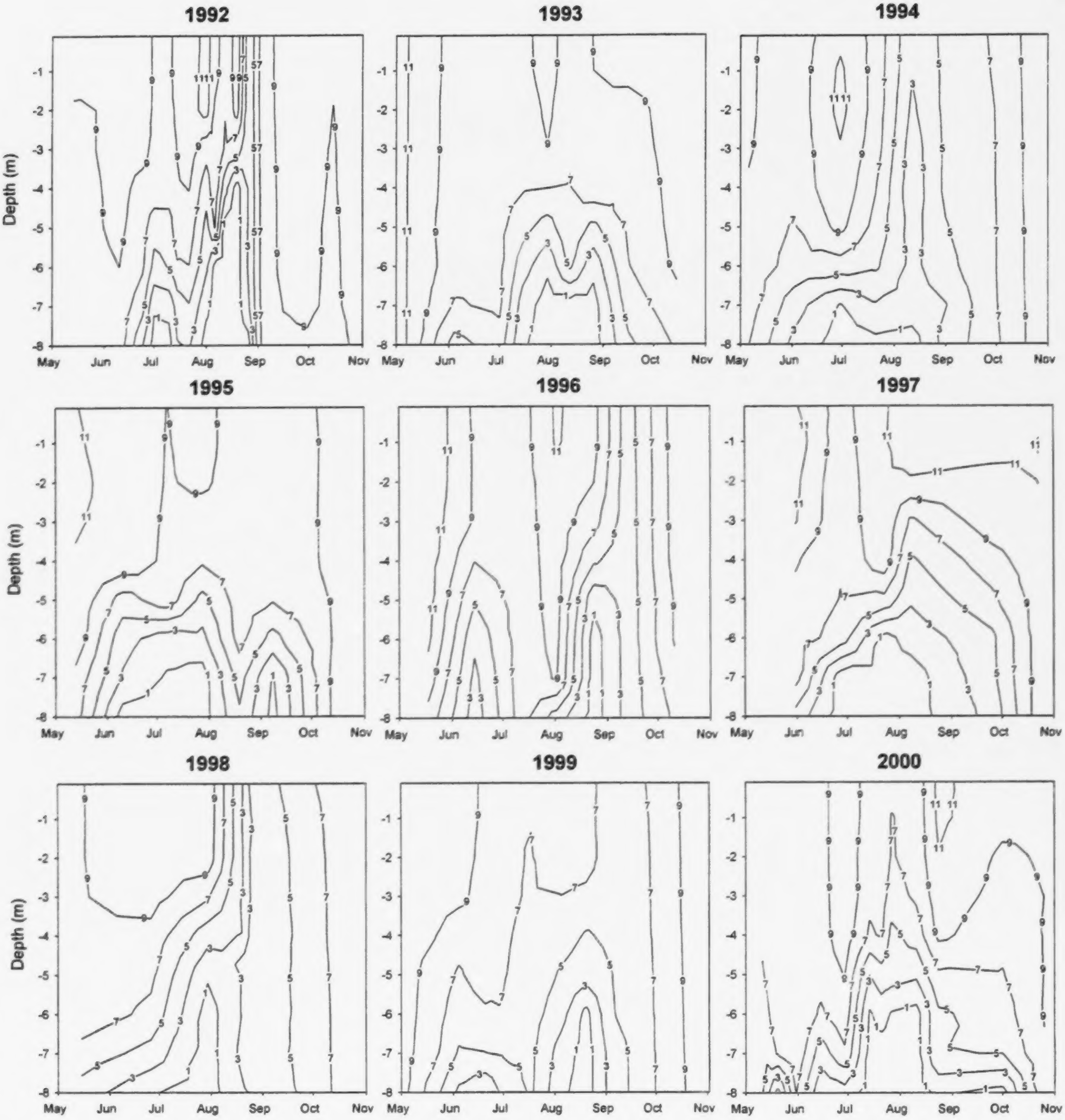


Figure 12 Dissolved oxygen (mg/L) isopleths for Pine Lake north basin, open water season, 1992-2000

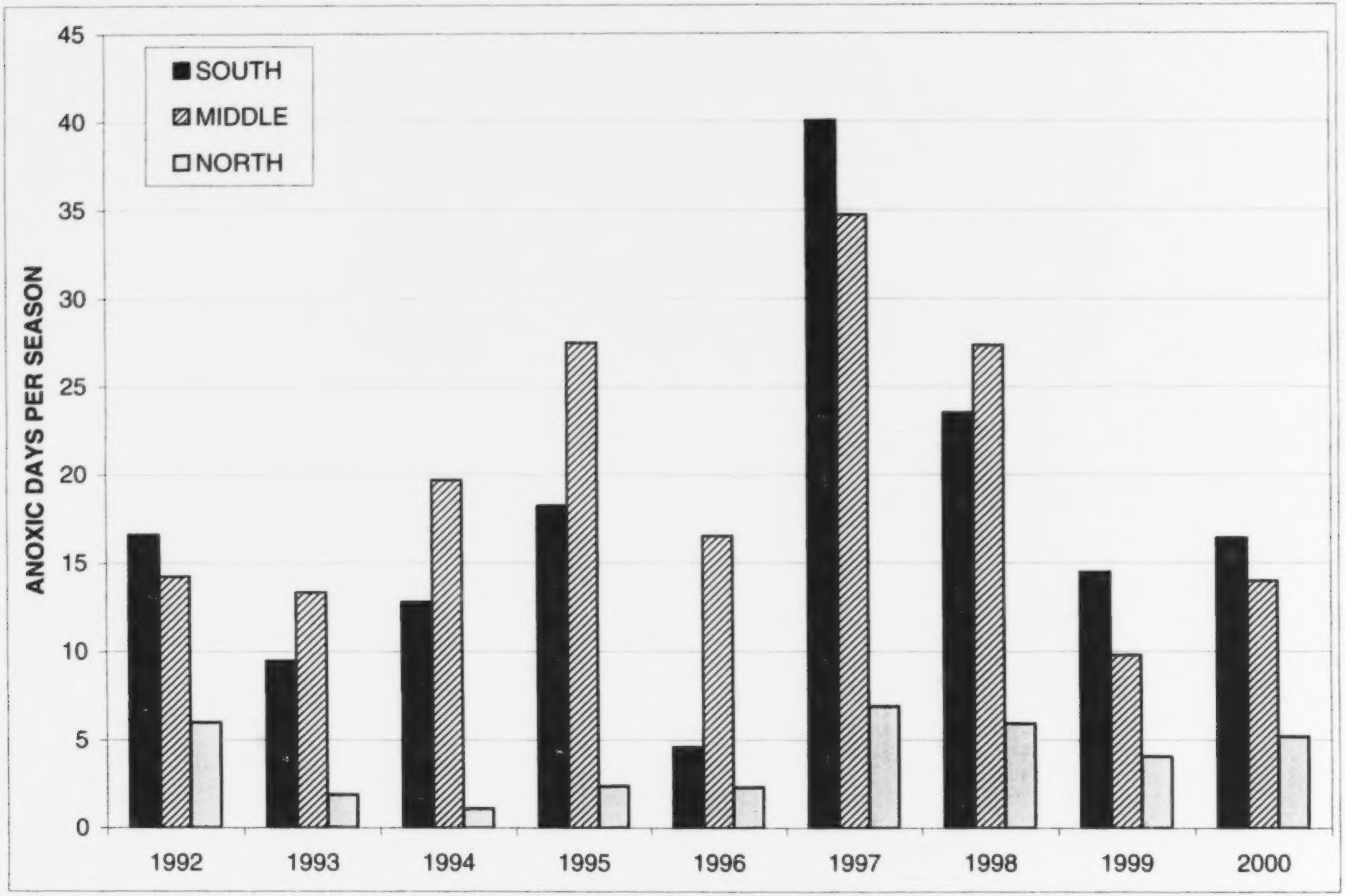


Figure 13 **Anoxic factors for Pine Lake during May to October, 1992-2000**

≥ 1.0 mg/L during the February sampling trip over the entire water column in the middle basin each year during 1998 - 2000 (Figure 14). Preliminary results suggest this trend towards improved winter dissolved oxygen continues, as neither the middle (≥ 2.91 mg/L) nor the south basin (≥ 3.03 mg/L) was anoxic on February 21, 2001. Prior to hypolimnetic withdrawal, the bottom water of the north and middle basin was anoxic during 1993-1997. In 1997, the entire water column at the north basin profile site was anoxic. Dissolved oxygen concentrations in the south basin have not improved to the same extent as the middle basin since 1998.

The reason that dissolved oxygen has improved in the winter in the middle basin of Pine Lake, but not during the open water season, is not understood. Changes over time in algal respiration and photosynthesis during the winter seem unlikely to account for the observed trend in winter dissolved oxygen concentration. Phytoplankton chlorophyll *a* just under the ice in the middle basin declined from a maximum value of 2.7 µg/L in 1992 to 0.2 - 0.4 during 1998-2000. However, these chlorophyll *a* measurements are all very low, and should have little influence on dissolved oxygen concentration. Although snowfall on February 26, 1998 (3 cm)(Innisfail East, AENV Station 05CE801) was well below the long-term average for the late winter (13 cm, *N* = 25), snowfall was near or above this average on March 2, 1999 and March 1, 2000 (17 cm, 12 cm, respectively). Accordingly, declining snowfall, increased availability of light, and increased photosynthesis seem unlikely to account for improved dissolved oxygen in winter. Similarly, all but one set of oxygen profiles during 1993 to 2000 was measured during mid-day (10:08 – 14:09). Accordingly, the time of sampling does not appear to be an important factor.

The most plausible explanation for improved dissolved oxygen in winter is that oxygen demand has declined following the observed decline in phytoplankton biomass in summer (Section 3.2.5). During the open water season, changes in oxygen demand would be less apparent due to mixing of the water column and intermittent stratification.

3.2.3 Phosphorus

Phosphorus is an essential plant nutrient. However, excessive phosphorus can cause an increase in the growth of aquatic plants such as algae. TP includes both particulate and dissolved forms of this nutrient, and is the most commonly measured form of phosphorus in lakes. Total dissolved phosphorus (TDP) is a better indicator of the amount of phosphorus available for aquatic plant growth than TP (Bradford and Peters 1987). Orthophosphorus (SRP) is the only form of phosphorus that may be directly utilized by aquatic plants (Wetzel 1983).

TP concentrations in the euphotic zone increased significantly from 1978 (*N* = 5) to 1995 (*N* = 7), and peak concentrations occurred in all the three basins during 1993, 1994, and 1996 (Figure 15). TP levels were unusually low in 1995 in all three basins of Pine Lake (Figure 16), perhaps because runoff to the lake, and presumably TP loading from the watershed, was well below average that year (Figure 3). Another possible explanation for unusually low TP concentration in 1995 is that less mixing of the water column, and movement of TP from the hypolimnion, occurred that year. As will be discussed later in this section, there was appreciable internal loading in 1995. The large decline in TP concentration (but not TP mass, Figure 17) in 1995 demonstrates the extent to which TP concentration can naturally fluctuate from year to year.

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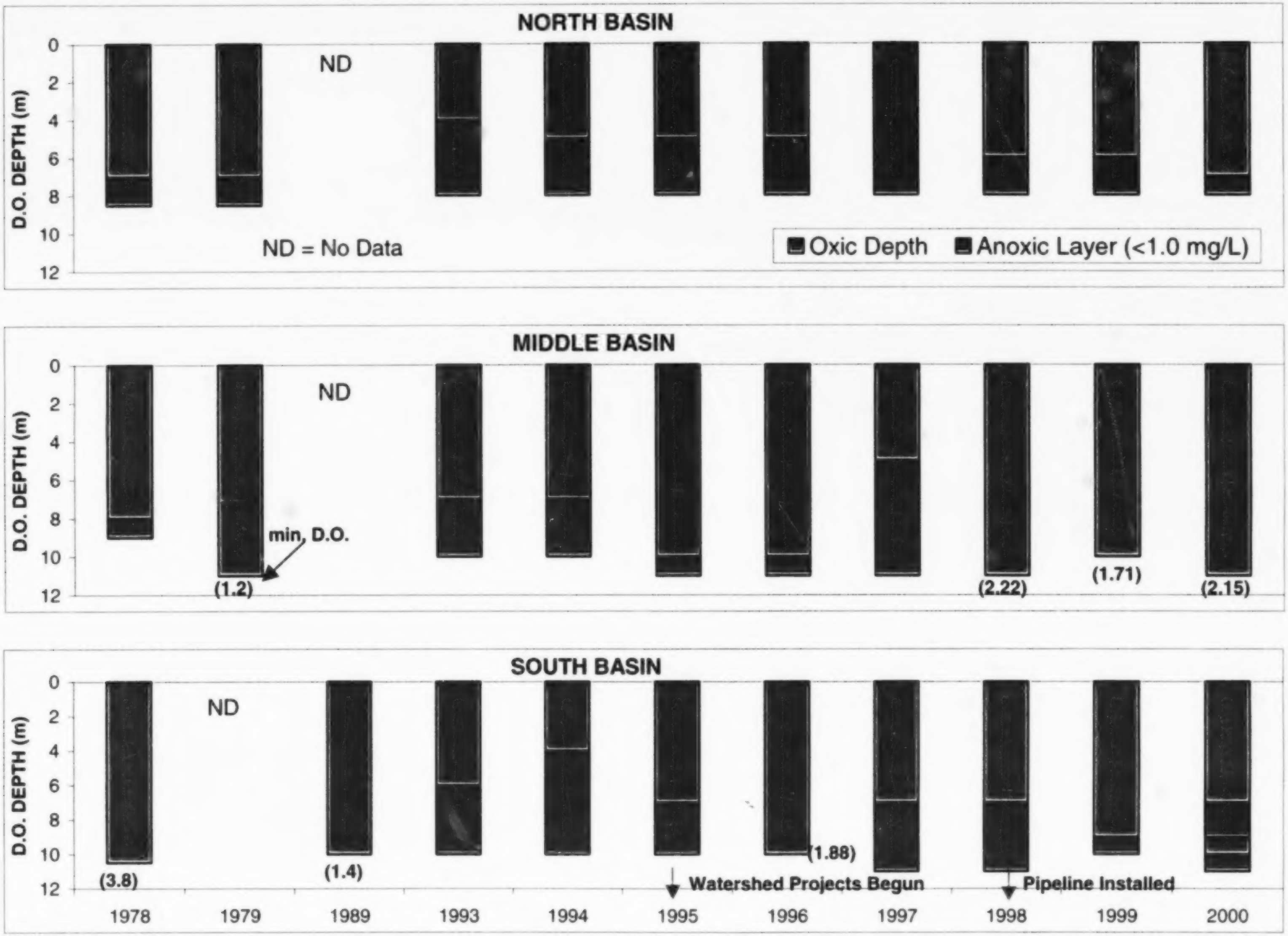

Figure 14 Dissolved oxygen profiles (mg/L) under ice at three sites on Pine Lake during February 1978-2000

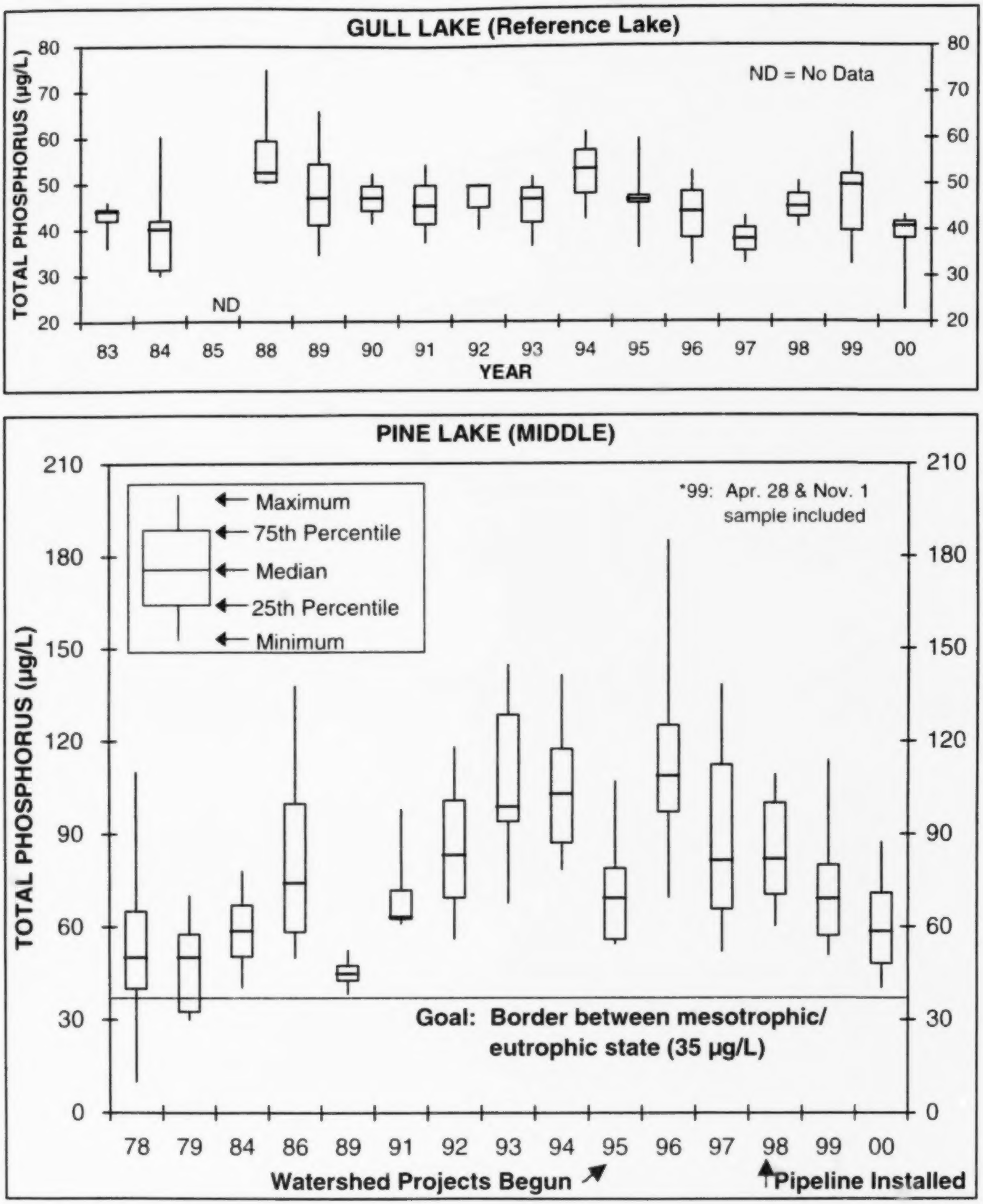

Figure 15 Euphotic zone composite total phosphorus (May-Oct) in Gull Lake and Pine Lake

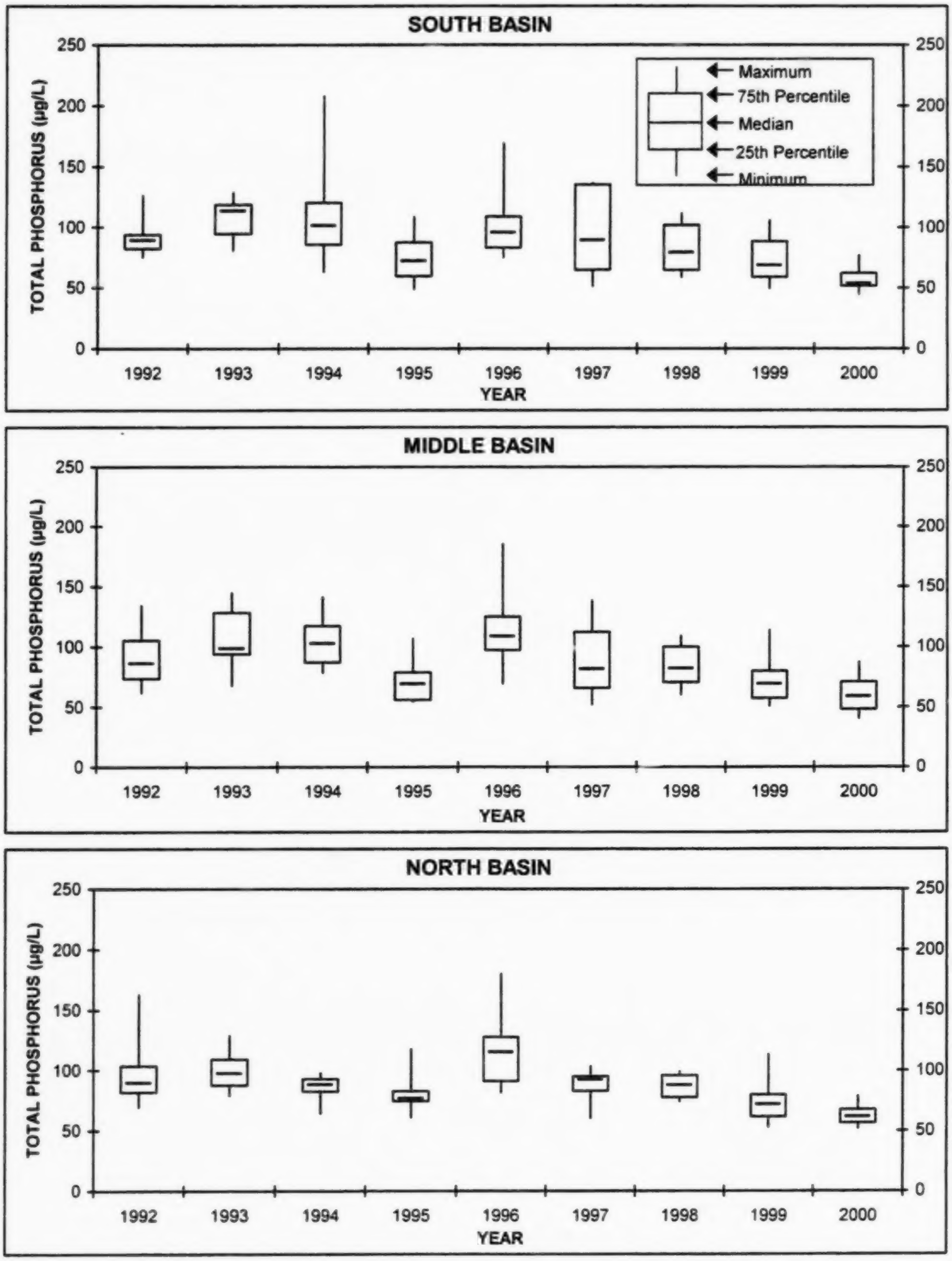

Figure 16 Euphotic zone composite total phosphorus in the three basins of Pine Lake, 1992-2000

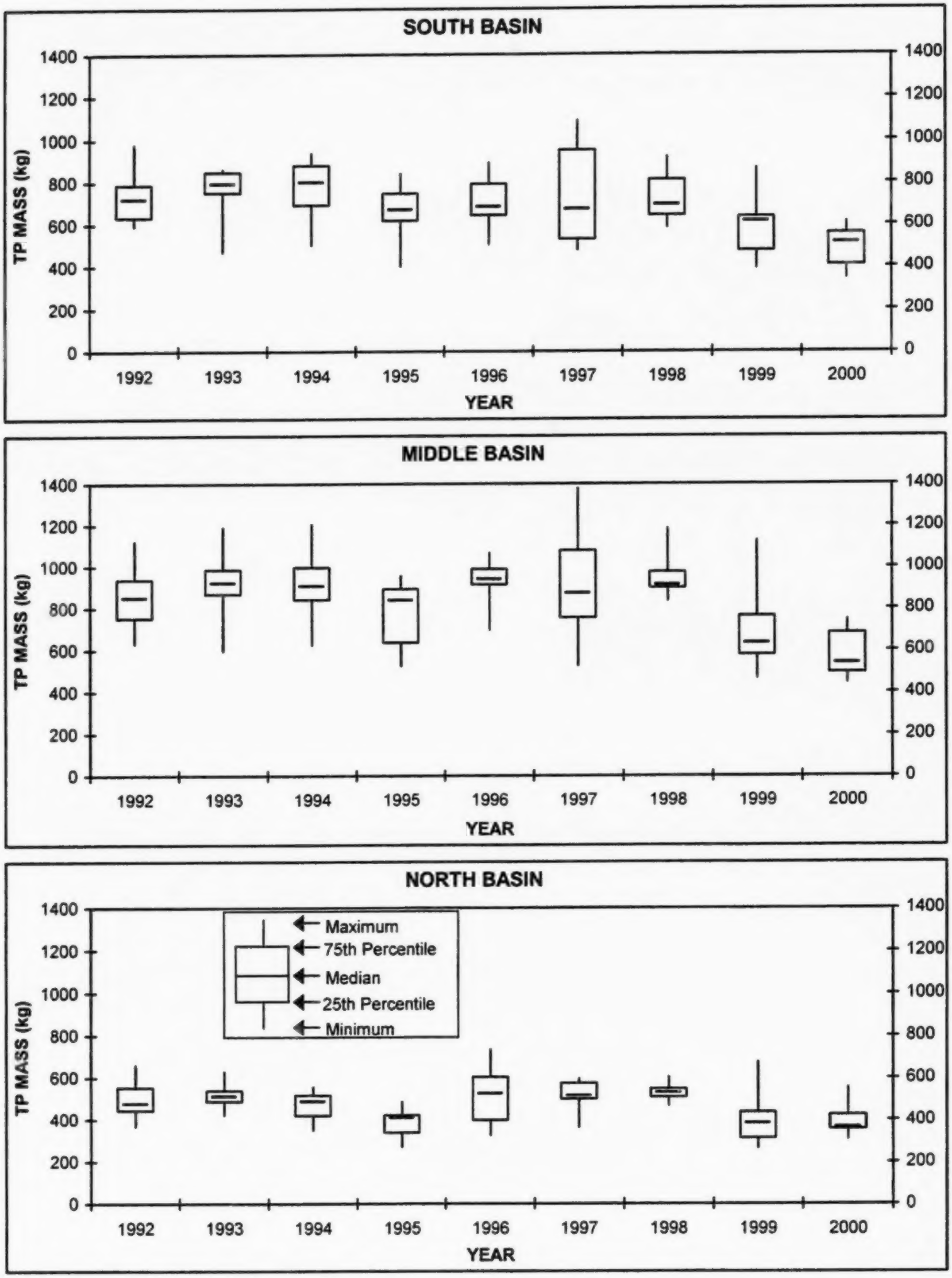

Figure 17 Total phosphorus mass in the three basins of Pine Lake, 1992-2000

3.2.3.1 Comparisons Among Lakes

Since 1996, TP concentrations have declined significantly in Pine Lake by 44 to 47% in the three basins (Figure 15)(Table 4). The median TP concentration in the middle basin was lower in 2000 (58.3 μg/L)($N = 12$) than in any year since 1984 (Figure 15). Preliminary median TP concentrations in the three basins in 2001 (range 61.5 – 72.8 μg/L) were similar to concentrations during 1999 and 2000 (range 58.3 – 71.5 μg/L). There is no evidence to date of a general decline in TP concentration since 1996 in Alberta lakes, due to natural factors, that could adequately explain the decline in TP at Pine Lake. In contrast to the declining trend in phosphorus concentration at Pine Lake during 1996 - 2000, there was no significant trend detected in TP concentration at Gull Lake after 1996 (Figure 15)(Table 4). Of the other nine reference lakes, median TP concentration in North Buck Lake declined by 21% during 1996 - 2000 (Figure 18), which is less than half the decline in TP concentration at Pine Lake (≥ 44%) during the same time period. Otherwise there were no consistent declining trends in TP concentration during 1996 – 2000 at any of the nine other lakes at provincial parks (Figure 18). However, it should be noted TP levels may naturally increase and decline over time in productive lakes in Alberta without lake management programs to control phosphorus loading. For example, TP levels peaked in Long and Steele Lakes in 1990 – 1992 and have since generally declined (Figure 18).

3.2.3.2 Comparisons Within Pine Lake

From 1995 to 2000 median TP concentration was slightly higher each year in the north basin of Pine Lake (Figure 16), than in the other two basins. However, none of the small differences among basins in TP or chlorophyll *a* concentration were statistically significant except for 1986 (not plotted in Figure 16), when TP was significantly higher in the middle basin. Similarly, Secchi depth did not differ significantly between basins except in 1997, when Secchi depth was significantly lower in the north basin (Figure 33 in Section 3.2.6). The lower Secchi depth in the north basin that year could reflect wind-blown accumulations of cyanobacteria that year. Spectral imaging revealed surface accumulations of cyanobacteria in the north basin in 1992 (Sosiak and Trew 1996).

Table 4 Significant monotonic trends in total phosphorus, chlorophyll *a*, and Secchi depth in the middle basin of Pine Lake and a reference lake (Gull Lake)

Sites	Sen Slope (Units/Year) for Significant Trends			
	Time Period	Total Phosphorus (μg/L)	Chlorophyll *a* (μg/L)	Secchi Depth (m)
Pine Lake	**1978-1995**	**+2.757**	**+0.800**	**NS**
Gull Lake	1988-1995	NS[b]	NS	NS
Pine Lake	**1996-2000**	**-14.661**	**-2.722**	**+0.358**
Gull Lake	1996-2000	NS	NS	NS

[a] Dashed line separates trends before and after the restoration program at Pine Lake

[b] NS: no statistically-significant trend detected at $\alpha = 0.10$

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Gull Lake	1996-2000	NS	NS	NS

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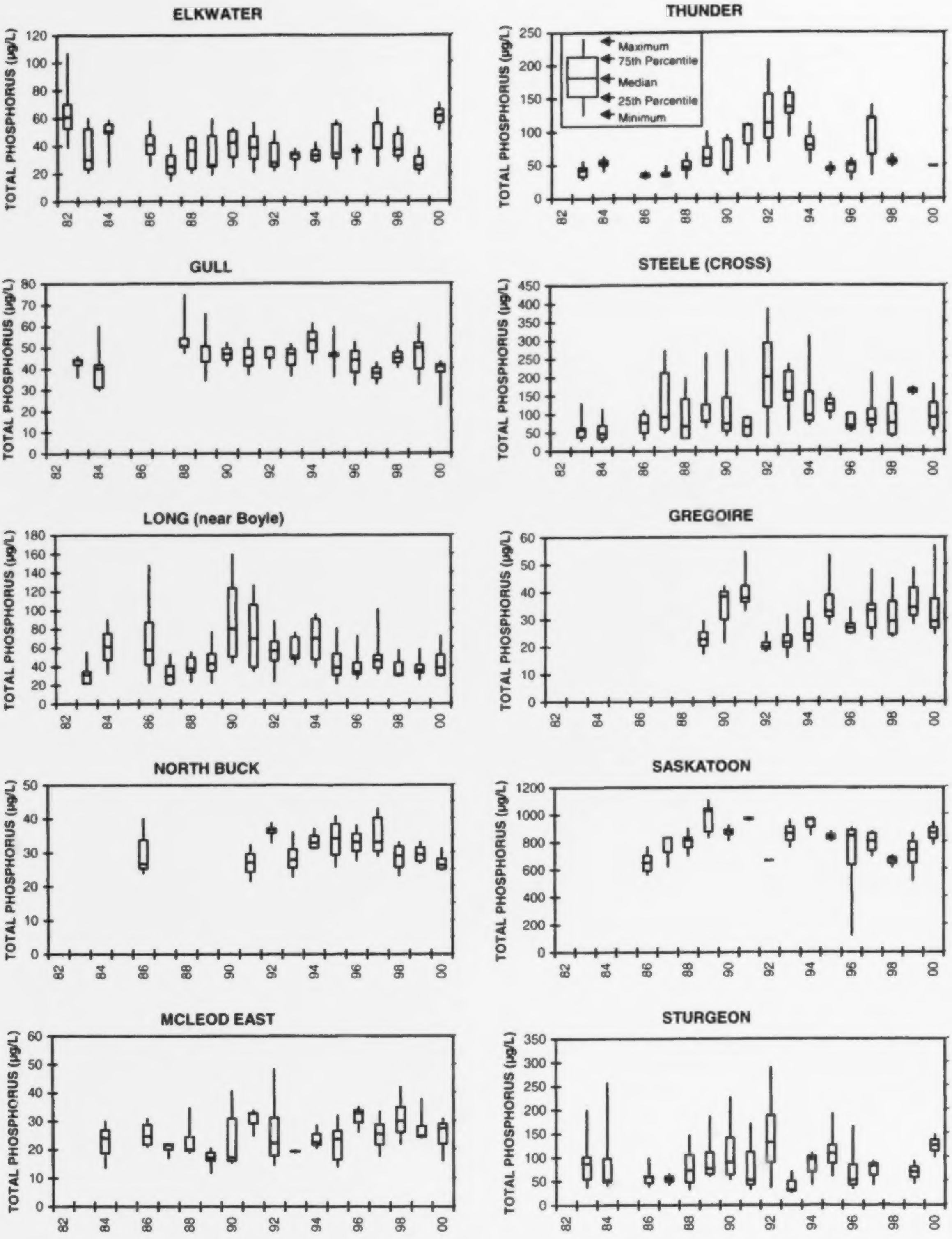


Figure 18 Euphotic zone total phosphorus (May-Oct) in 10 provincial park lakes in Alberta

This analysis found little evidence of statistically significant spatial variation in the concentration of these three water quality variables in the 15 years sampled during 1978 - 2000. Accordingly there is no indication that one basin has been more affected by the restoration program or other factors to date. However, hypolimnetic withdrawal from the south basin could deplete sediment phosphorus there and cause more spatial variation in water quality among basins in future.

Isopleths have been used to illustrate the release of phosphorus from sediments during the open water season (Figures 19 to 21). In these figures, lines that denote equal concentration over time are 30 μg/L apart and concentrations increase at greater depth. Isopleth labels overlap in years with high internal loading.

Figures 19 to 21 demonstrate that appreciable sediment phosphorus release occurred nearly every summer in Pine Lake, although the pattern varied somewhat between basins and between years. The highest TP concentrations occurred in hypolimnetic waters of the middle and south basins in 1994, 1995 and 1998 (range of peak concentrations 0.323 – 0.588 mg/L). Sediment phosphorus release in most basins was interrupted by lake mixing in at least 1992 and 1999, and surprisingly little phosphorus release was detected in the south and middle basins in 1997 (Figure 19 and 20). As discussed in Section 3.2.1 water temperatures in the hypolimnion were lower in those basins in 1997 (maximum measurement: 13.53°C) than in any other year. These lower temperatures may have reduced sediment phosphorus release rates, even though a prolonged period of anoxia occurred in those basins. Water temperatures in the hypolimnion of the north basin were higher that year than the other basins, up to 19.75°C on August 6, 1997 (Figures 7 to 9), and some sediment phosphorus release occurred there during anoxia (Figure 21).

3.2.3.3 Total Phosphorus Mass

The total mass of TP throughout the water column of Pine Lake varied less from year to year during 1992 to 1998 than euphotic zone TP concentration. Peak TP mass over the entire lake ranged between 2284 (1995) and 3063 kg (1997) during those years, a difference of only 779 kg (Figure 17). Peak TP mass did not decline as much as euphotic zone TP concentration in 1995, because there was high internal loading to bottom waters that year. Peak TP mass each year has been used as an indicator of the total TP mass available in Pine Lake, because these estimates reflect the net cumulative increase in mass over the open water season from internal and external phosphorus loading, minus any loss to hypolimnetic withdrawal and Ghostpine Creek.

Following the restoration program, peak TP mass over the entire lake dropped by 781 kg (-29%) during 1996 to 2000 to 1912 kg, the lowest mass estimate during the sampling program. The percent decline in mass in the south, middle and north basins, over the same time period was -31.5%, -30.1%, and -24.5%, respectively. The rate of decline in TP mass was greatest from 1998 to 2000 during hypolimnetic withdrawal.

The decline in TP mass in the south and middle basins was probably due to the effects of hypolimnetic withdrawal, reduced nutrient loading due to watershed projects on tributaries to those basins (Table 1), and TP export over the weir to Ghostpine Creek. The respective impacts on lake TP mass of these watershed projects and hypolimnetic withdrawal cannot be determined

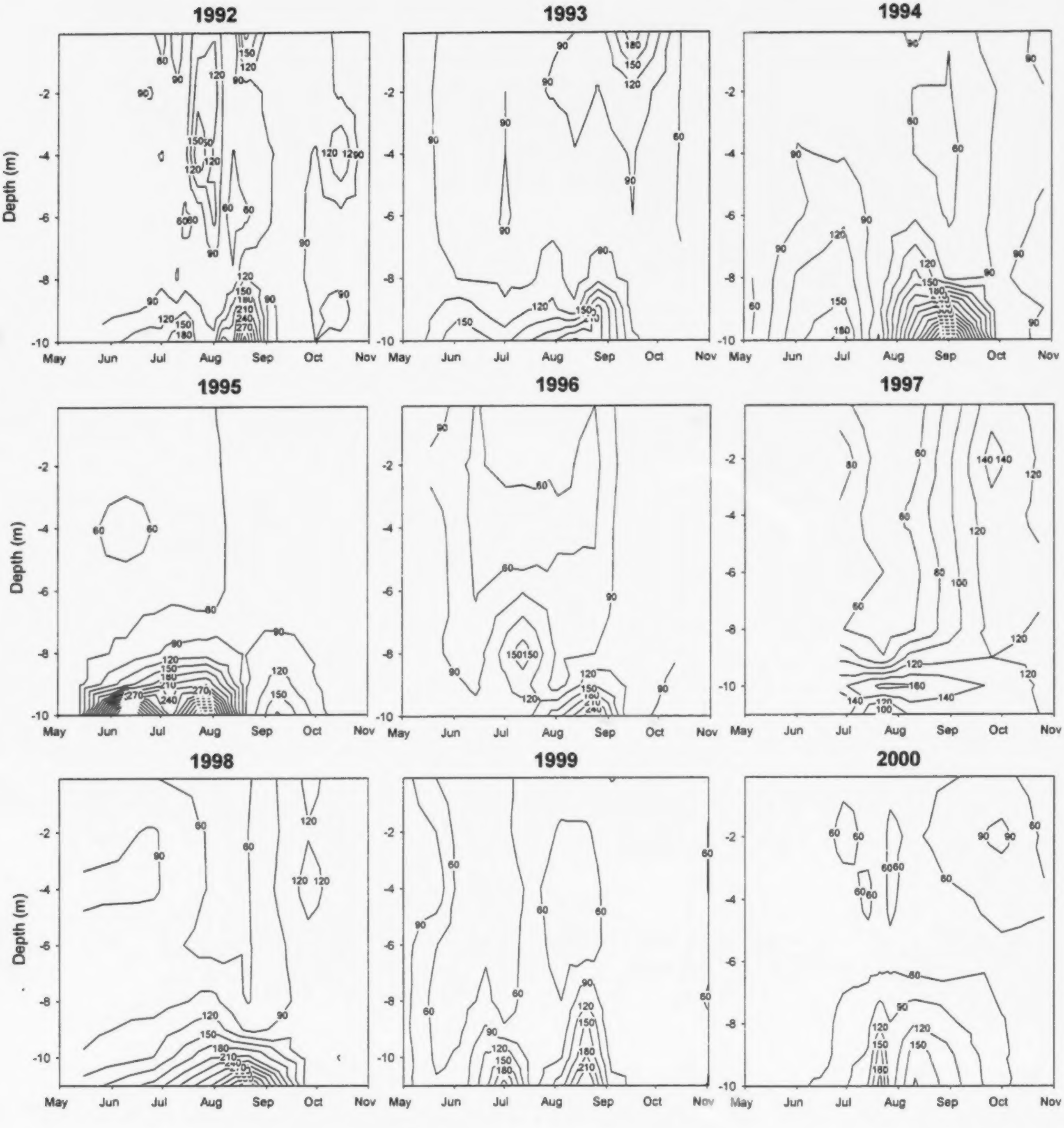


Figure 19 Total phosphorus (mg/L) isopleths for Pine Lake south basin, open water season, 1992-2000

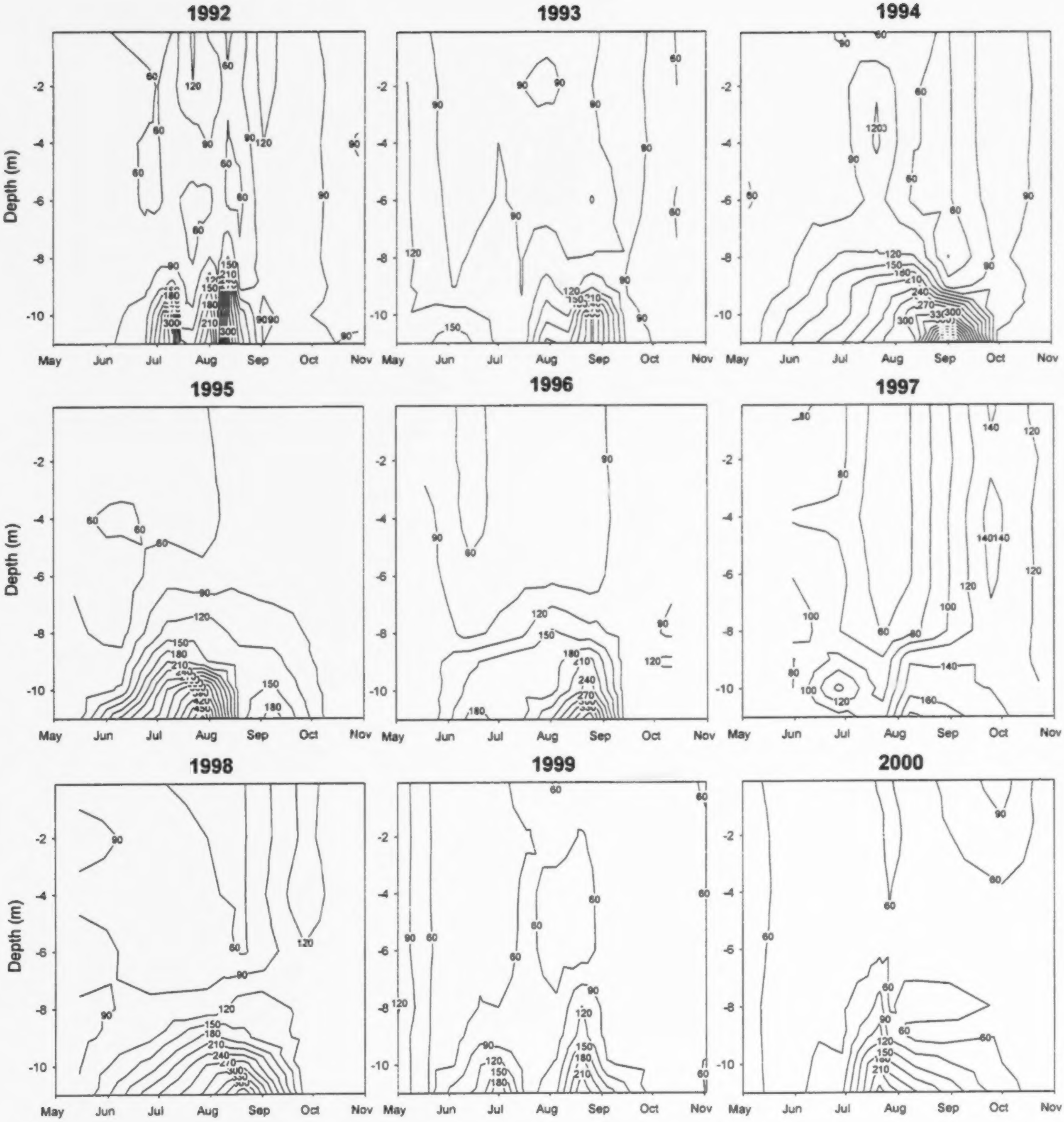


Figure 20 Total phosphorus (mg/L) isopleths for Pine Lake middle basin, open water season, 1992-2000

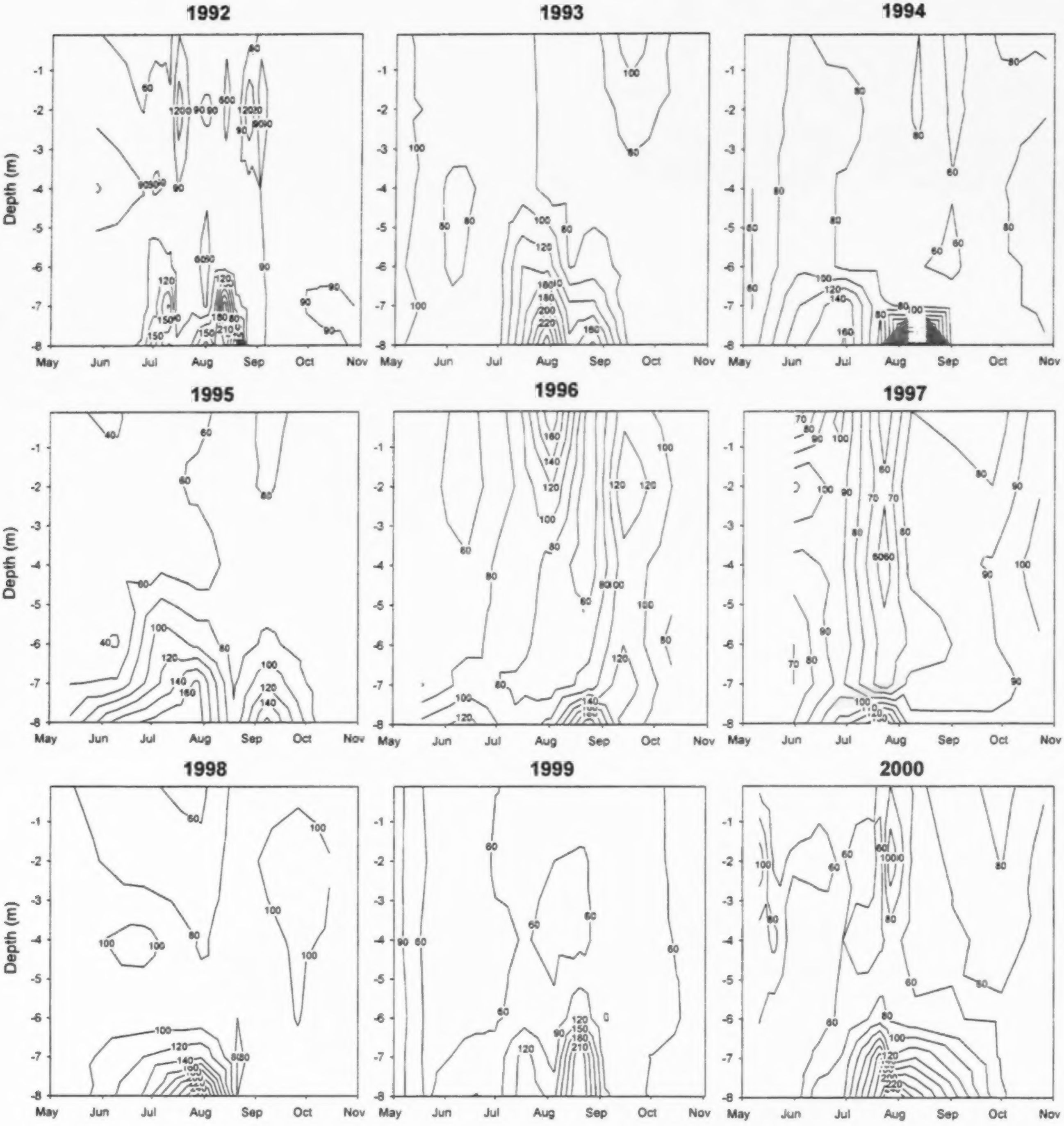


Figure 21 Total phosphorus (mg/L) isopleths for Pine Lake north basin, open water season, 1992-2000

accurately because changes in tributary phosphorus loading since 1992 cannot be estimated, and TP export over the weir could not be estimated for 1999. However, hypolimnetic withdrawal in 1999 and 2000 exported at least 229 kg TP to Ghostpine Creek, or about 29% of the 794 kg decline in peak TP mass from 1998 to 2000. The additional TDP mass exported to Ghostpine Creek during hypolimnetic withdrawal in 2000 is further evaluated in Section 3.3.

Whispering Pine Golf and Country Club Resort withdrew 12,729 m^3 from about 3.7 depth in June 1999, and 25,296 m^3 from about 11 m in June 2000. This water contained an estimated 0.69 and 1.92 kg TP, which are relatively small amounts. If water levels had allowed the resort to take the maximum amount allowed under their license (68,200 m^3) in late July during the period of maximum internal phosphorus loading (Figure 20), this irrigation withdrawal could have removed 16.27 kg TP from Pine Lake. It is not possible to predict the period of peak internal loading in advance, but withdrawal of irrigation water during late July or August, rather than June, would probably remove more phosphorus. Water withdrawal by the Whispering Pine Golf and Country Club Resort during the period of maximum internal loading would probably increase TP removal. However, water withdrawal by the resort would have to be coordinated with hypolimnetic withdrawal to maintain the target lake levels in both licenses.

TDP concentrations generally increased in the euphotic zone of each basin of Pine Lake from 1992 to 1998 (Figure 22). TDP levels then declined in each basin in 1999 and 2000, during hypolimnetic withdrawal. Median TDP concentrations were lower in each basin in 1997 than in the adjoining years. Lower TDP concentrations in 1997 may be caused by a lower rate of sediment release of dissolved phosphorus that year, as described above in Section 3.2.3. As with TDP, median SRP concentrations peaked during 1997 - 1998, and then declined during hypolimnetic withdrawal (Figure 23). SRP levels were also relatively high in each basin in 1993.

The lowest median TP concentration in the euphotic zone of Pine Lake in 2000 (53.4 μg/L in the south basin)(Figure 16) was still well above the 35 μg/L fixed boundary between mesotrophic and eutrophic states (OECD 1982). However, as will be discussed in Section 3.2.5 and 3.2.6, other indicators of trophic state such as chlorophyll *a* and Secchi depth in 2000 were much closer to the assumed natural concentrations.

3.2.4 Nitrogen

Nitrogen is another essential nutrient for aquatic plants. Excessive nitrogen can also lead to increased growth of aquatic plants, and the same concerns associated with phosphorus. In addition, high levels of nitrate can impair drinking water quality, and ammonia and nitrite may be toxic to aquatic life. Total kjeldahl nitrogen (TKN) measures both ammonia and organic nitrogen, while total nitrogen (TN) includes TKN and nitrite+nitrate, which are often analyzed together.

Nitrogen concentrations did not decline to the same extent as phosphorus following the restoration program. Median TN in the euphotic zone increased from 1.35 - 1.48 mg/L in 1978 to 1984 (Mitchell and Sosiak 1991), to peak concentrations of 2.26 mg/L in the middle basin in 1992 (Figure 24, Appendix I). TN thereafter fluctuated in concentration at lower levels than in

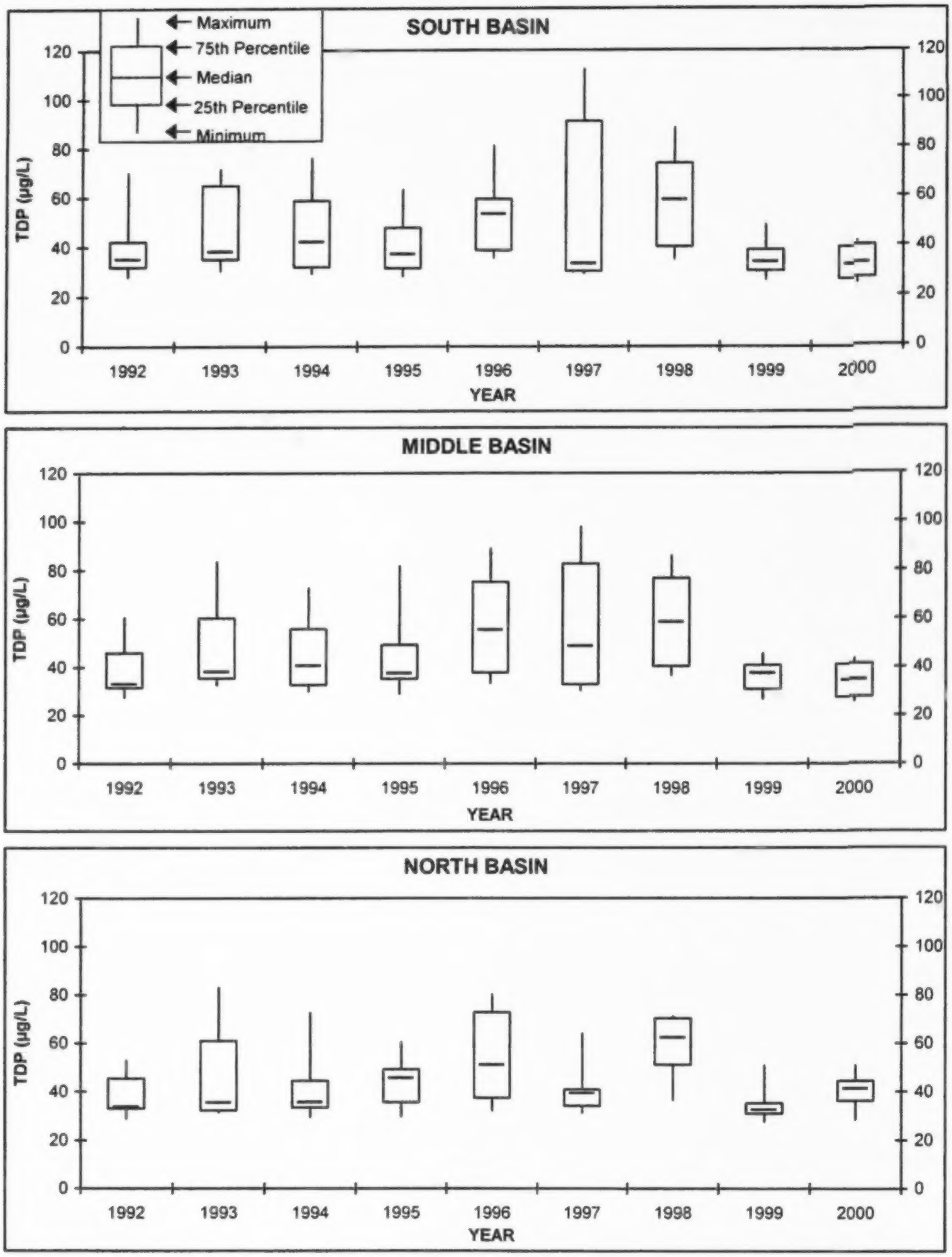
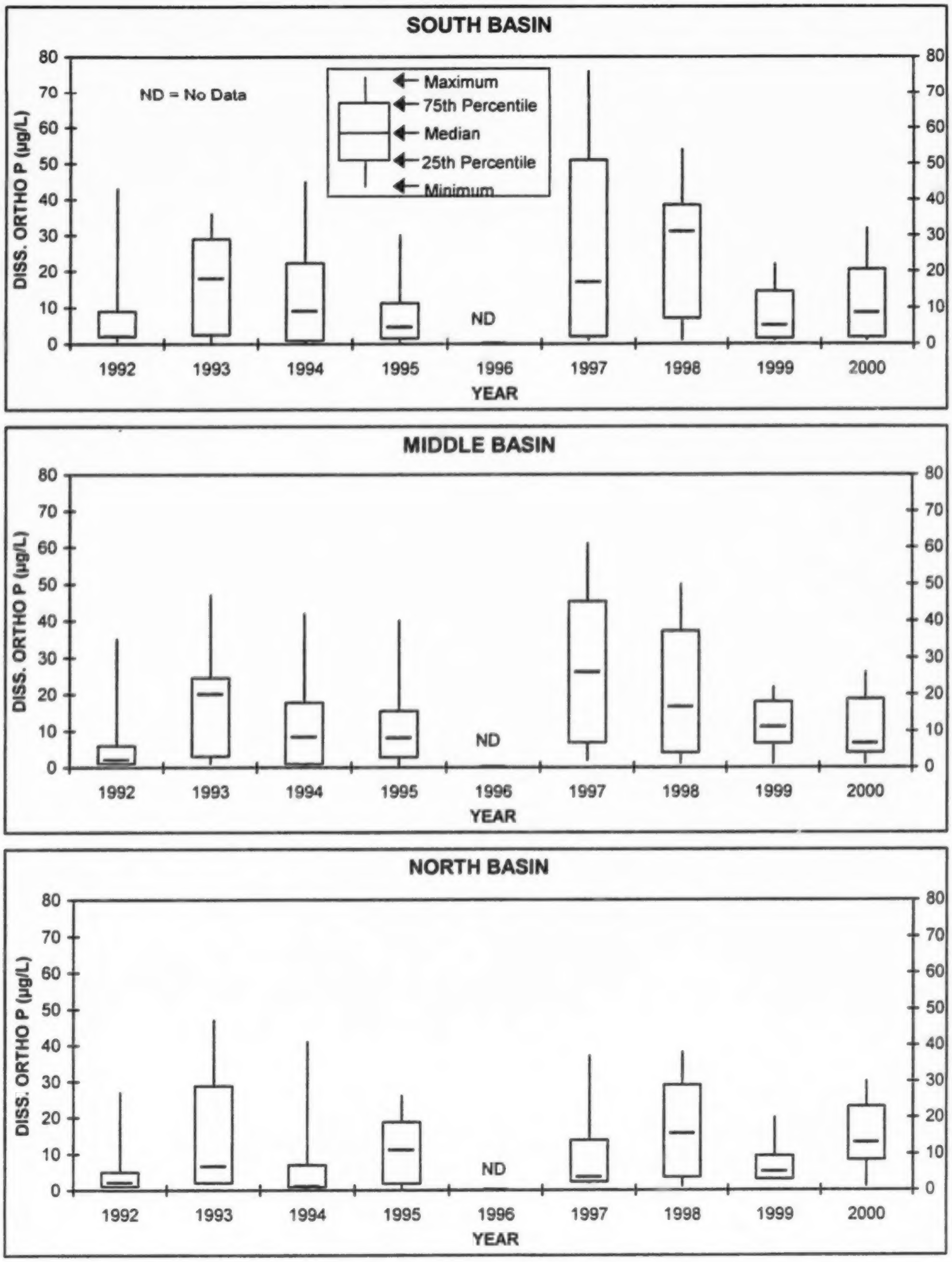


Figure 22 Euphotic zone composite total dissolved phosphorus in the three basins of Pine Lake, 1992-2000


SOUTH BASIN

MIDDLE BASIN

NORTH BASIN

Figure 23 **Euphotic zone composite dissolved ortho phosphorus in the three basins of Pine Lake, 1992-2000**

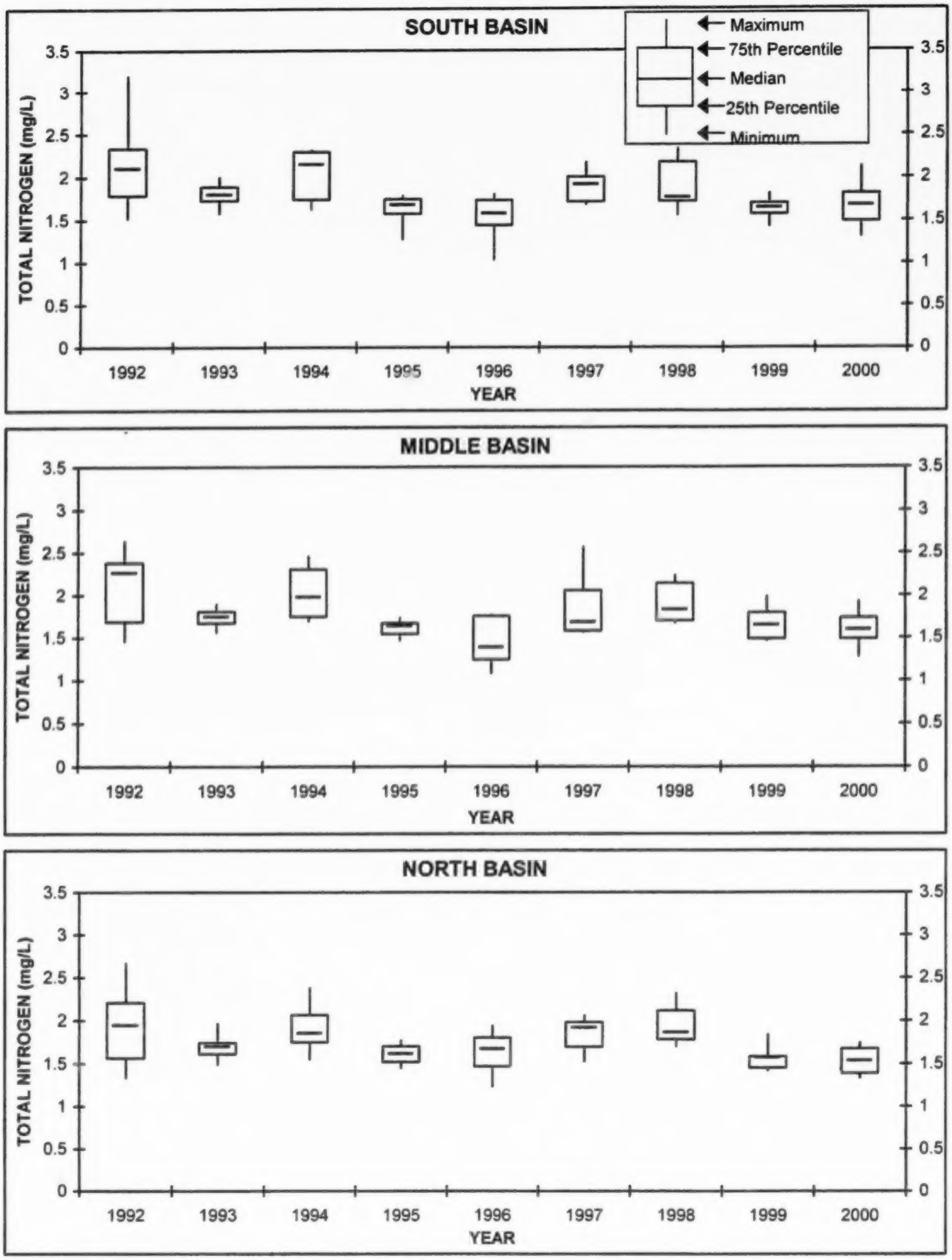


Figure 24 **Euphotic zone composite total nitrogen in the three basins of Pine Lake, 1992-2000**

1992. Most of this TN was organic nitrogen. The concentration of TKN, which was mainly organic nitrogen, closely followed changes in TN over time (Figure 25). The relatively high levels of organic nitrogen in Pine Lake are probably caused by the decomposition of nitrogen-fixing cyanobacteria, whose biomass also peaked in 1992 (Section 3.2.5) and temporarily declined in 1995. Levels of nitrite and nitrite+nitrate (range: 0.003 – 0.026 mg/L) were remarkably low throughout the sampling program (Figure 26 and 27, Appendix I). Low levels of these variables are typical of Alberta lakes (Mitchell and Prepas 1990).

Ammonia concentrations in the euphotic zone were generally highest during 1996 – 1998 but were highly variable (Figure 28). Ammonia remained high in some basins until 1998, and thereafter declined. Ammonia and other forms of nitrogen were sampled throughout the water column of Pine Lake during 1992 - 1995. Ammonia was generally much higher in the profundal waters of each basin than in surface waters; the highest concentration was 3.4 mg/L in the bottom layer of the north basin on August 10, 1994. These higher levels may be caused by sediment release of ammonia, and reduced nitrification under anaerobic conditions in the hypolimnion (Wetzel 1983). During fall turnover and weather-induced mixing events, ammonia levels sometimes increased in the surface waters of Pine Lake following the movement of ammonia from the hypolimnion. For example, median ammonia levels in the euphotic zone increased greatly during September and October, 1996 (Figure 28), when this variable exceeded the CCME guideline (0.33 mg/L)(CCME 2000) in consecutive composite samples (0.44, 0.40 mg/L).

3.2.5 Phytoplankton Chlorophyll a

Chlorophyll *a* is the most commonly used biological indicator of phytoplankton biomass and trophic status in lakes (Cooke et al. 1993). Median chlorophyll *a* increased significantly in Pine Lake from levels just above the boundary between mesotrophic and eutrophic states in 1978 and 1979 to peak concentrations in 1992, when median chlorophyll *a* ranged between 39.4 and 48.2 µg/L (maximum 163 µg/L) in the three basins (Figure 29 and 30, Appendix I). Based on chlorophyll *a*, Pine Lake was classified as hypereutrophic in 1992 (Sosiak and Trew 1996), which indicates an extremely high level of algal productivity, and frequent impairment of recreational use.

High median levels of chlorophyll *a* occurred in all basins of Pine Lake during 1992 to 1994, then declined significantly from 1996 to 2000 (-58% middle basin) (Figure 27 and 28). Preliminary median chlorophyll *a* concentrations in the three basins in 2001 (range 13.0 – 17.0 µg/L) were slightly higher than median concentrations during 1999 and 2000 (range 7.5 – 14.9 µg/L, but well below concentrations during 1992 to 1994.

There were no significant trends in the reference lake in the same ecoregion (Gull Lake)($P >$ 0.10) before or after 1996 (Table 4). Similarly, chlorophyll *a* did not decline during 1996 - 2000 in seven other lakes in various ecoregions of Alberta, but did decline in McLeod Lake East (-75%) and North Buck Lake (-22%) over this time period (Figure 31). Since TP did not similarly decline at McLeod Lake East during this time period, the reason for the apparent decline in chlorophyll *a* at this lake is not known. These two lakes (*N*: 3 - 6) were sampled far

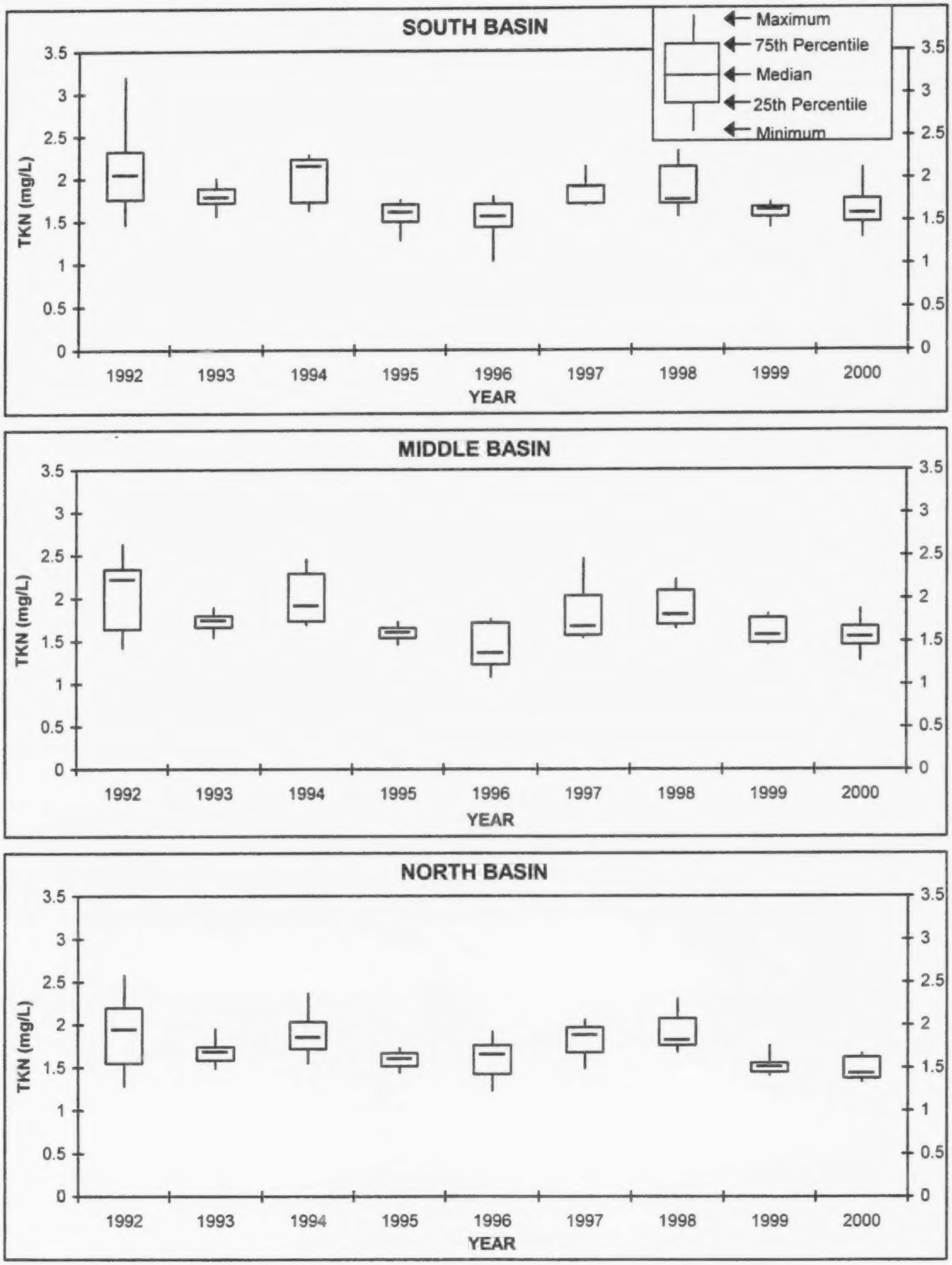


Figure 25 Euphotic zone composite total kjeldahl nitrogen in the three basins of Pine Lake, 1992-2000

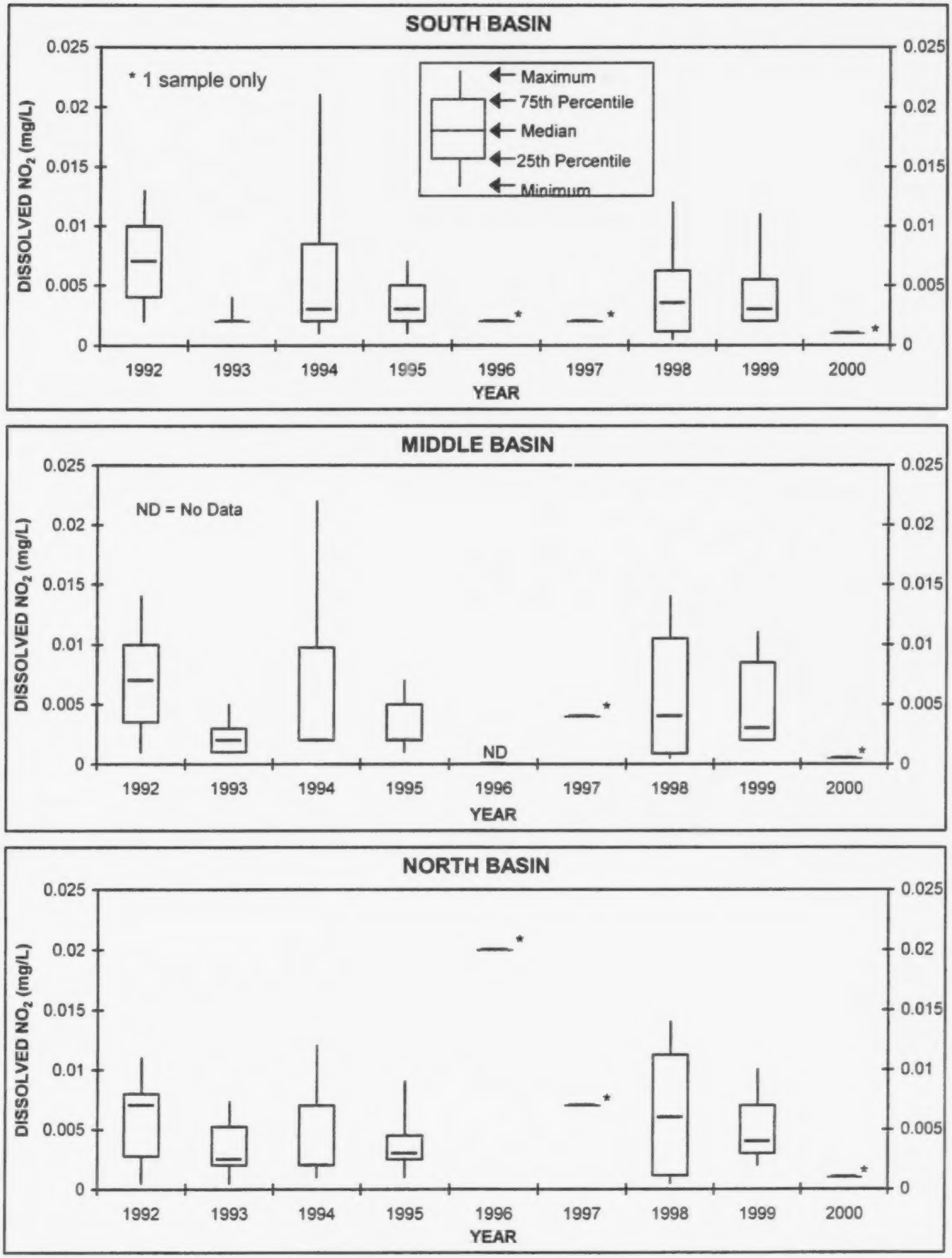


Figure 26 Euphotic zone composite dissolved nitrite nitrogen in the three basins of Pine Lake, 1992-2000

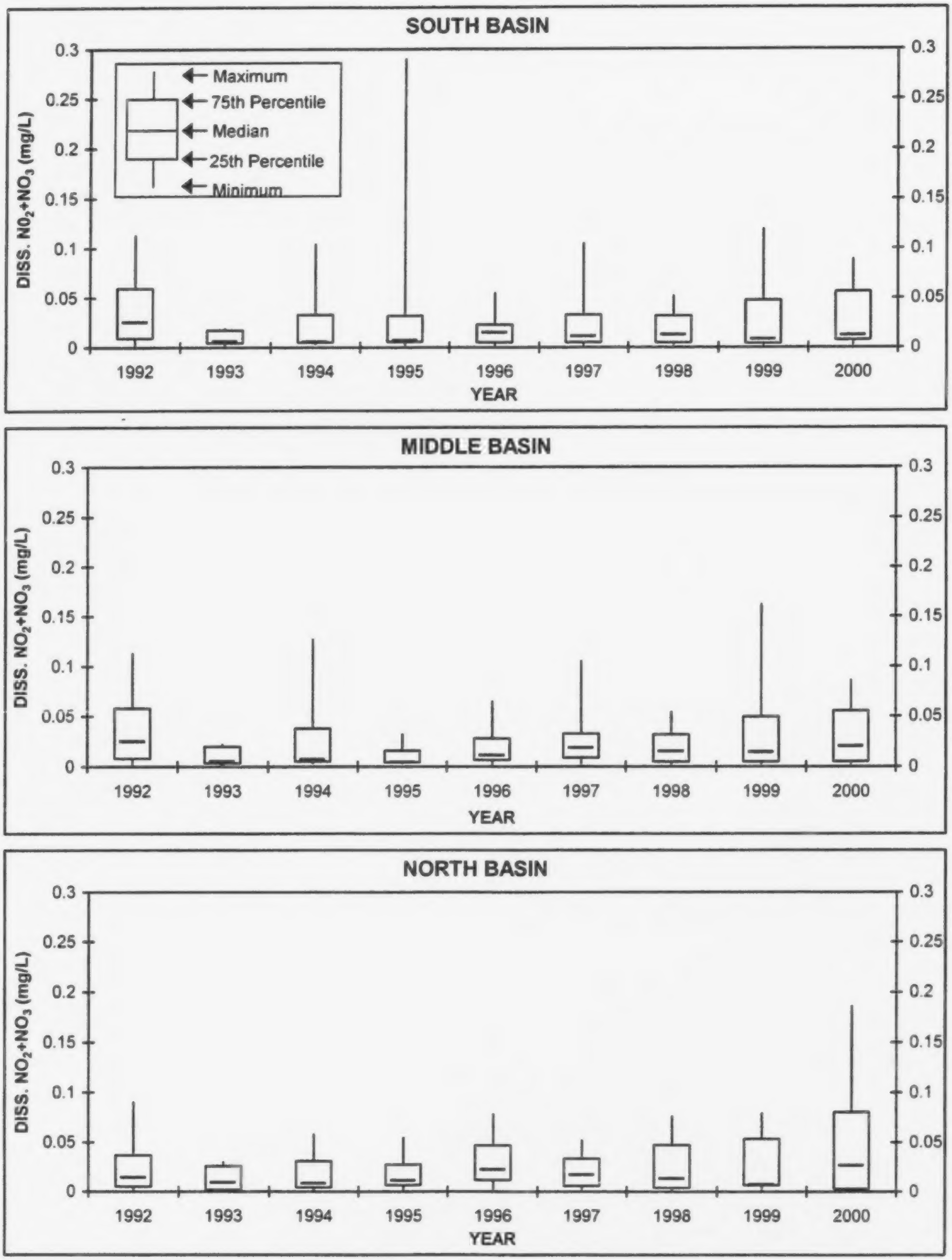


Figure 27 **Euphotic zone composite dissolved nitrite+nitrate nitrogen in the three basins of Pine Lake, 1992-2000**

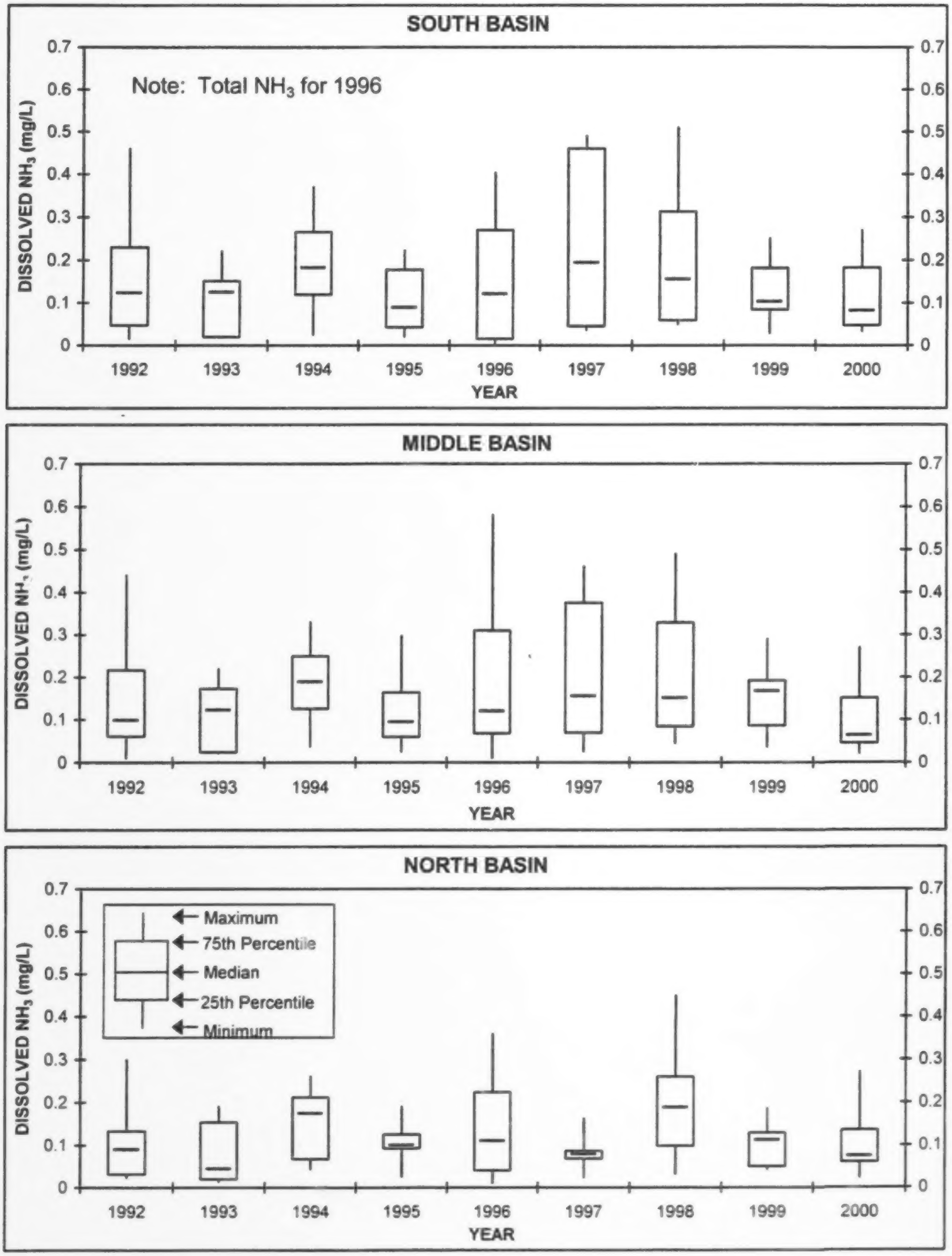


Figure 28 **Euphotic zone composite dissolved ammonia nitrogen in the three basins of Pine Lake, 1992-2000**

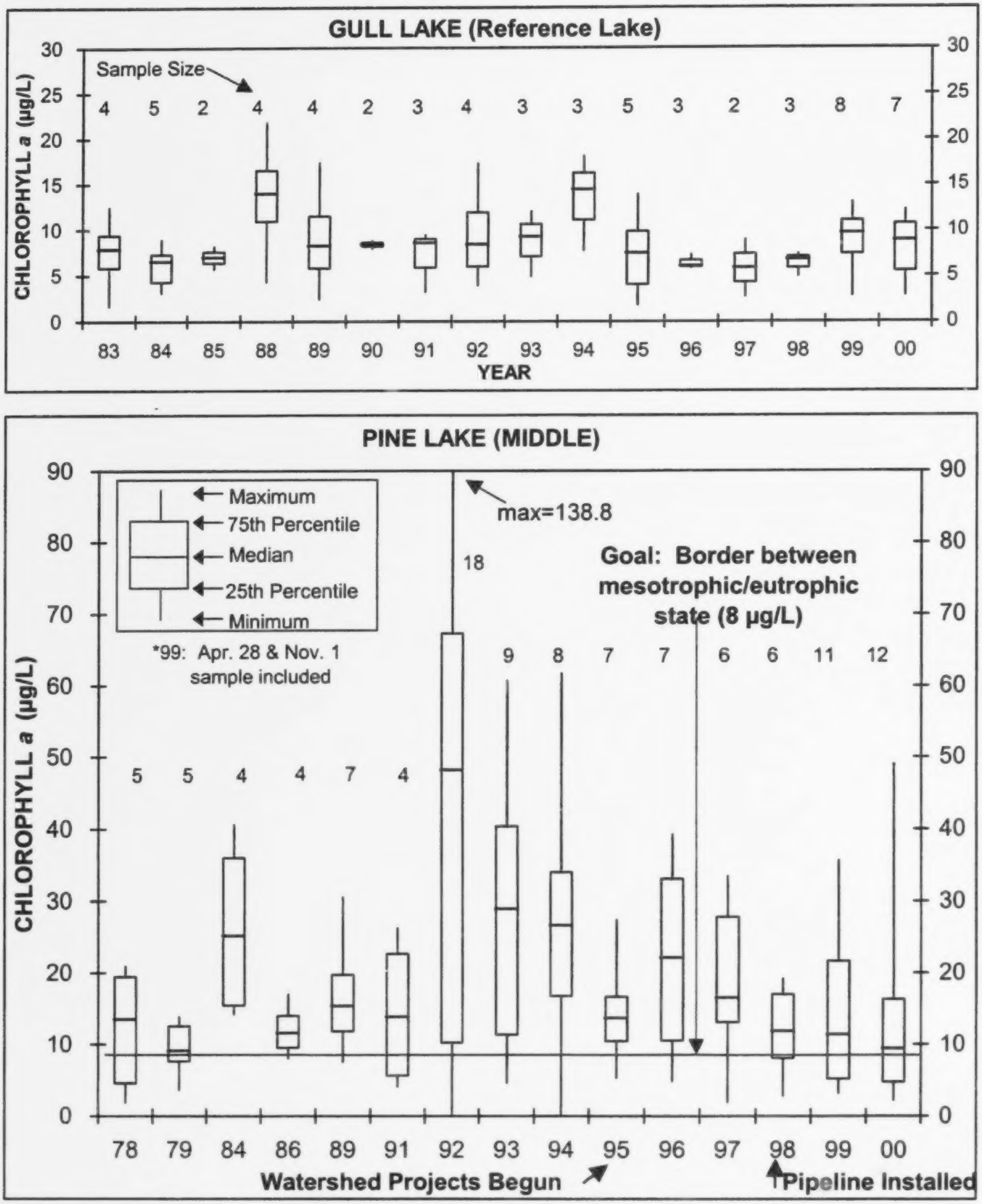


Figure 29 Euphotic zone composite chlorophyll *a* (May-Oct) in Gull Lake and Pine Lake

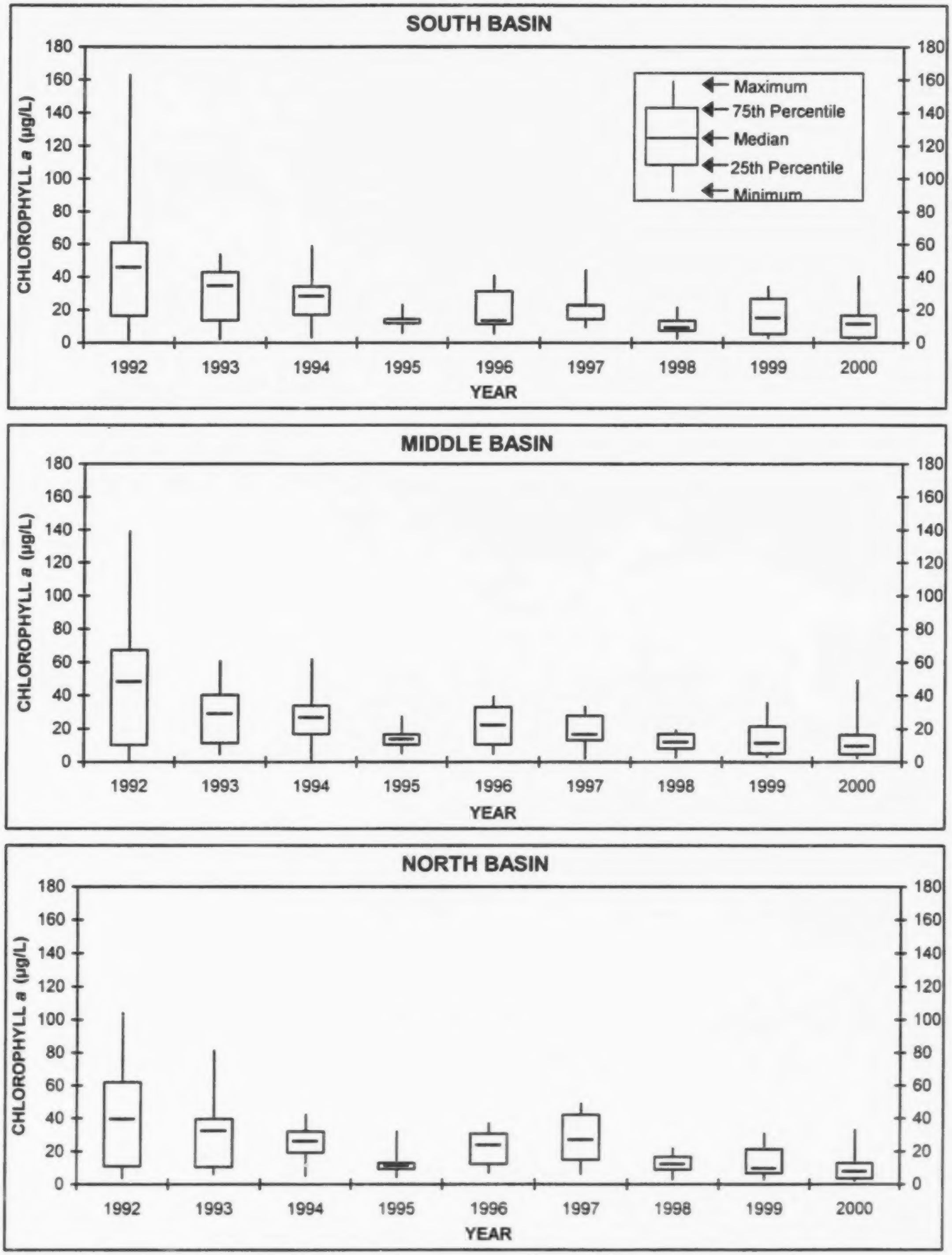


Figure 30 **Euphotic zone composite chlorophyll *a* in the three basins of Pine Lake, 1992-2000**

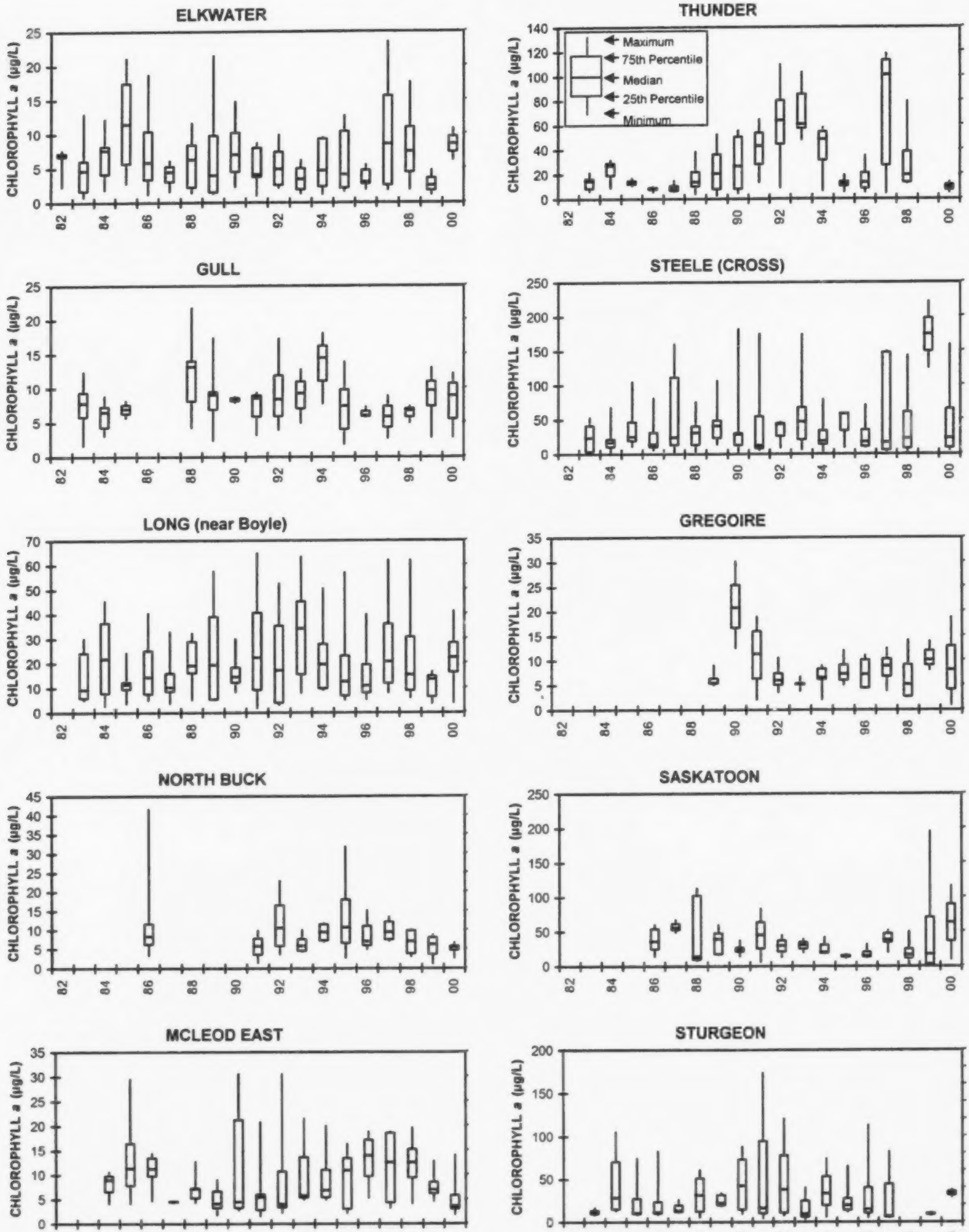


Figure 31 Euphotic zone composite chlorophyll *a* (May-Oct) in 10 provincial park lakes in Alberta

less frequently than Pine Lake (*N*: 6 - 12) during this time period, and results could be less representative of actual water quality in these two reference lakes. There appears to be no evidence of a widespread decline in nutrients and chlorophyll *a* in Alberta lakes since 1996 that could account for the improvements in chlorophyll *a* at Pine Lake. However, it should be noted that levels of chlorophyll *a* may naturally fluctuate in lakes in Alberta without lake management programs to control phosphorus loading. For example, chlorophyll *a* levels gradually increased from 1989 to 1996 in McLeod Lake East, then declined as described above.

Unlike TP, median chlorophyll *a* was below the meso-eutrophic boundary (8.0 µg/L) in 2000 in the north basin (7.5 µg/L), and approached this boundary in the other two basins (middle: 9.3, south: 11.1 µg/L). This suggests that phytoplankton biomass in Pine Lake approached levels that may have occurred naturally in 2000.

Although median TP was slightly higher in the north basin than the other two basins during 1996 - 2000 (Figure 16), median chlorophyll *a* was highest in the middle basin over the long-term (1992-2000 median: 18.1 µg/L) and lowest in the north basin (1992-2000 median: 14.1 µg/L)(Figure 30). However, these small differences in chlorophyll *a* concentrations among the three basins were not statistically significant in any year. As demonstrated by spectral imaging, and sampling to assess spatial variation (Sosiak and Trew 1996), there is considerable spatial heterogeneity of chlorophyll *a* in Pine Lake. Surface films of cyanobacteria that form in a basin with higher nutrient levels may be moved by the wind to other basins. Differences between years in wind direction, and other weather conditions, may cause temporary spatial variation in the distribution of chlorophyll *a* of Pine Lake.

As indicated on Figure 29, Pine Lake was sampled more frequently in 1992 than in any other year. This high frequency of sampling probably increased the likelihood of sampling during periods of higher or lower algal biomass. However, median concentrations from 1992 are probably not biased by sampling frequency, since monthly sub-samples from the middle basin had a median concentration (47.2 µg/L) that is similar to the median of the entire dataset (48.2 µg/L). The unusually high algal biomass in 1992 was attributed to an early spring break-up that year, and longer growing season for phytoplankton (Sosiak and Trew 1996).

As sometimes occurs in highly productive lakes in Alberta (e.g., Nakamun Lake, Sosiak and Trew 1996), algal biomass fluctuated from year to year for reasons that are poorly understood. Along with TP (Section 3.2.3), chlorophyll *a* was unusually low in 1995, before most restoration work had begun. Furthermore, algal blooms occurred as expected even in years with relatively low median chlorophyll *a* and TP such as 1999 and 2000. During the algal blooms in the summer of 1999, the dominant species of phytoplankton included *Gleotrichia* sp. (S. Watson. 1999. Personal communication), a type of cyanobacteria that was not identified in the samples collected in Pine Lake in 1992 (Watson 1993). Members of this genus can cause severe skin irritation (Prescott 1970), and may account for reports of skin rashes in 1999. Further monitoring of key water quality variables will be required to conclusively demonstrate that the large decline in chlorophyll *a*, and other variables, is mainly due to the restoration program and not merely a reflection of natural variation.

3.2.6 Secchi Depth

Secchi depth is widely measured as an indication of the transparency of lake water to light penetration. Secchi depth is the mean depth at which a weighted, black and white disc disappears and reappears when lowered into a lake. Low Secchi depth measurements are generally indicative of more turbid conditions caused by algal blooms and other factors. Because Secchi depth measurements are prone to various sources of error, underwater photometers were routinely used to determine the depth of light penetration for composite sampling of Pine Lake.

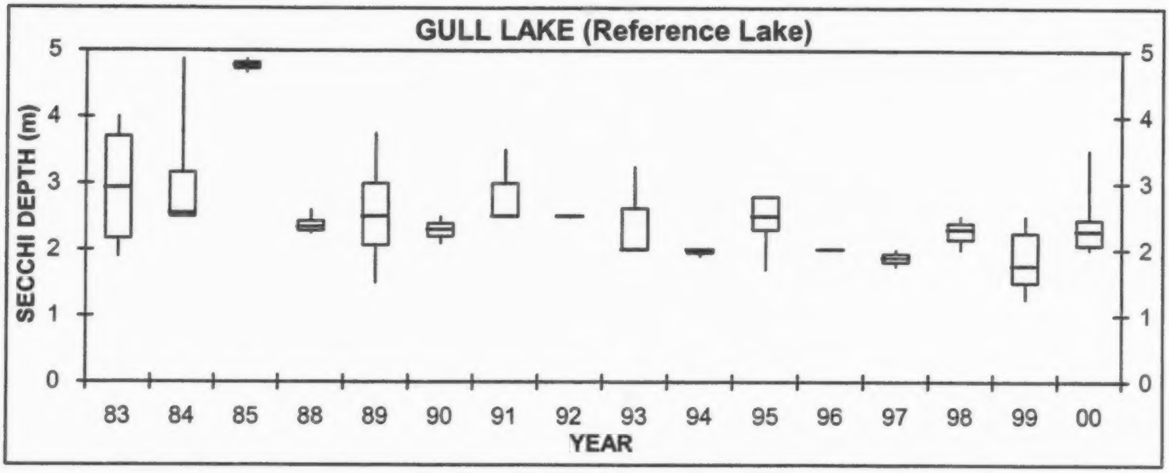
Secchi depth was lowest in Pine Lake in 1992, but there was no statistically significant trend in Secchi depth during 1978-1995 (Table 4). However, Secchi depth increased significantly during 1996 - 2000, which suggests that lake clarity improved as chlorophyll *a* declined during that time period (Figure 32). During the same time period, total suspended solids (as NFR) and turbidity in each basin have greatly declined (Appendix I). These variables confirm that water clarity has improved in Pine Lake in recent years. Preliminary median Secchi depth measurements in the three basins in 2001 (range 2.5 – 3.2 m) were similar to median depths during 1999 and 2000 (range 2.4 – 3.4 m).

In 2000, the median Secchi depth in the south basin (3.4 m) was over the meso-eutrophic boundary (3 m) that may represent natural conditions, and measurements approached this boundary in the other two basins (middle: 2.7 m, north: 2.8)(Figure 33). Secchi depth was significantly lower in the north basin in 1997, but otherwise there were no significant differences among basins in this variable in any year.

In contrast to the improvement in Secchi depth at Pine Lake during 1996 - 2000, there was no significant increase in Secchi depth at a reference lake (Gull Lake) during the same time period (Table 4)(Figure 32). Instead, Secchi depth has decreased significantly at Gull Lake over 1983 - 2000 (Sen slope: -0.05 m/yr), which suggests this lake has gradually become more turbid over time. Similarly, Secchi depth did not increase during 1996 - 2000 in seven other lakes in various other ecoregions of Alberta, but appears to have increased somewhat at McLeod Lake East and Elkwater Lake over this time period (Figure 34).

3.2.7 Major Ions

Some major ions and related variables appear to have increased over time in Pine Lake. Sodium, chloride, total dissolved solids (TDS) and alkalinity were higher in each basin in 1998 – 2000 than in 1992 – 1994 (Appendix I). Chloride remained well below the CCME guideline, while TDS sometimes exceeded the CCME irrigation guideline for the most sensitive crops in 2000 (three measurements > 500 mg/L in south basin, $N = 7$)(CCME 1999). Conductivity increased from 690 – 703 μS/cm in 1992 – 1994, to 711 – 724 μS/cm in 1998 – 2000 (Appendix I). Conductivity increases with an increased concentration of salts, and other solutes that conduct an electrical current. Accordingly, conductivity is another indication of the gradual increase in the concentration of some salts that has occurred over time. Because euphotic zone conductivity was not available in 2000, surface conductivity has been used in Appendix I. Magnesium levels decreased somewhat and there was no apparent change in other ions over the same time period.



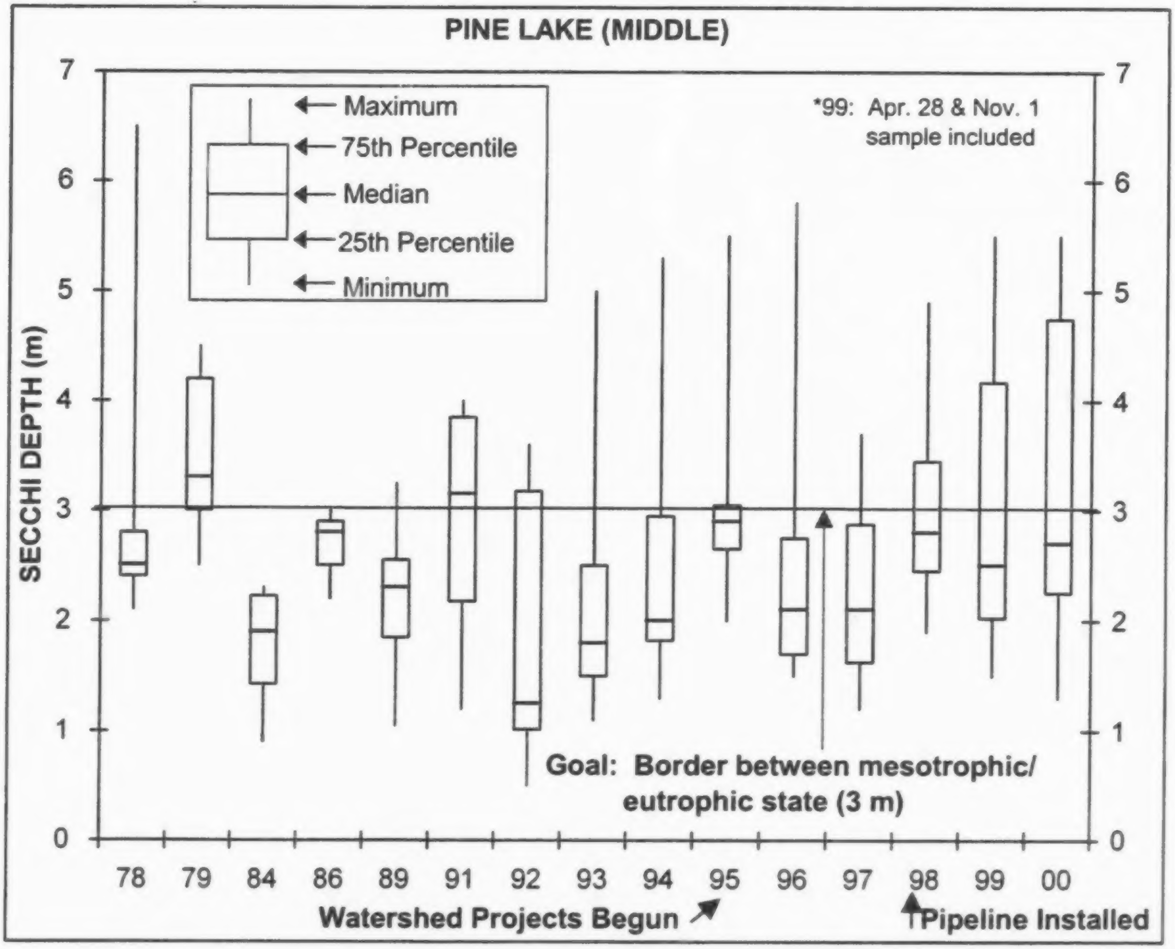


Figure 32 Secchi depth (May-Oct) in Gull Lake and Pine Lake

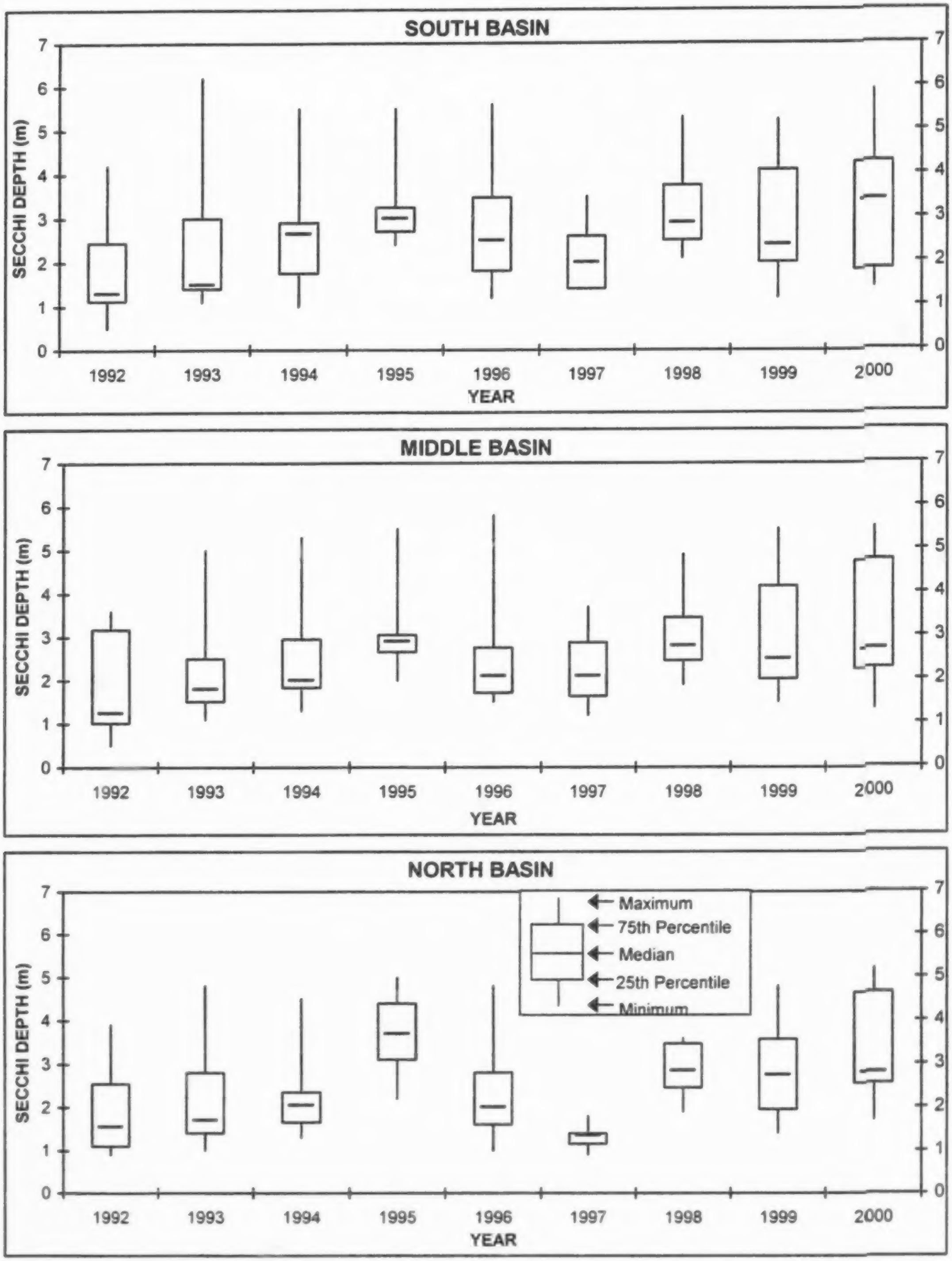


Figure 33 **Secchi depth in the three basins of Pine Lake, 1992-2000**

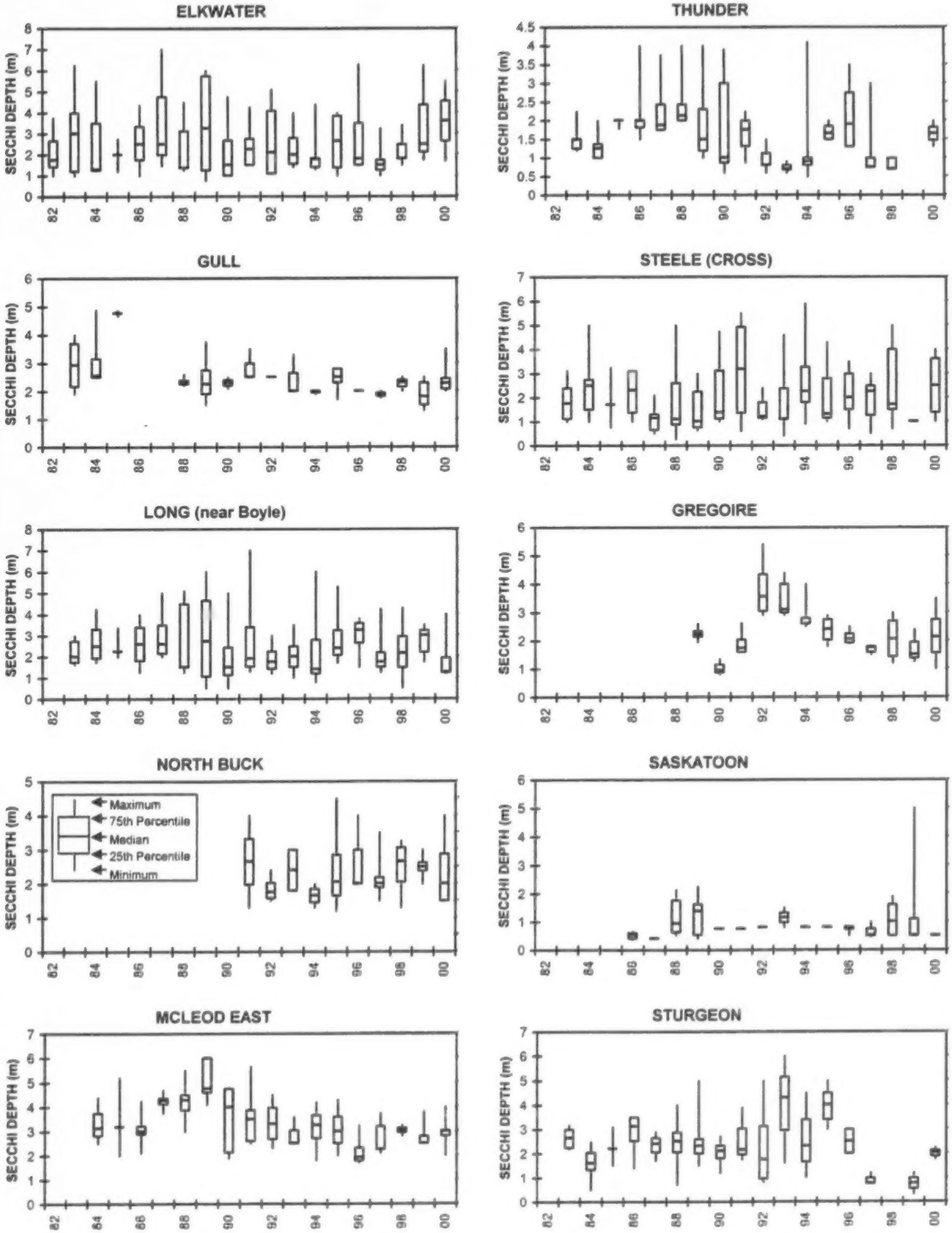


Figure 34 Euphotic zone Secchi depth (May-Oct) in 10 provincial park lakes in Alberta

The reason for these small changes in ion concentration is not known. Possible explanations could include changes in groundwater inflow to the lake, reduced calcite precipitation related to lower phytoplankton biomass, or reduced uptake of sodium by phytoplankton (Wetzel 1983). There has been no obvious change in runoff over the time period in question (Figure 3). However, some groundwater in the Pine Lake area is relatively high in sodium and TDS (Garven 1982). Increased inflow of saline groundwater to Pine Lake could alter the concentration of some ions in lake water. Sodium and chloride are relatively conservative ions that undergo relatively minor changes from most biological processes, however sodium requirements are relatively high for some of the types of cyanobacteria that occur in Pine Lake (Wetzel 1983).

3.3 Phosphorus Loading and Export from Pine Lake

Median TP concentration in Stream 6 declined greatly in 1996, one year after cattle were no longer wintered along that creek (Figure 35). No changes in TP concentration between 1992 and 1996 were apparent downstream from the second watershed project completed in 1995, on Stream 4, or at other stream sites. A longer time period may be required for nutrient concentrations to decrease downstream from the project on stream 4. The range of TP concentration at Stream 4 was far greater in 1992 than in 1996. This difference probably reflects more intensive daily sampling by automated sampling over the entire period of runoff in 1992, which was more apt to sample brief runoff events and other periods of high TP concentration. The 1996 results were grab samples, at most twice per week during peak runoff to June 12, collected by volunteers of the Pine Lake Restoration Society.

The results presented in Figure 35 are the only tributary sampling results available since projects were completed in the Pine Lake watershed. From 1996 to 1998 an additional four farm projects were completed and sewage treatment systems were installed or replaced at one camp and one resort. Other improvements in nutrient concentration have probably occurred in tributaries to Pine Lake. There have apparently been no assessments to date in Alberta of the effects of BMPs on nutrient loading to lakes. A detailed assessment of changes in nutrient loading following the various watershed projects on Pine Lake tributaries should be completed. This sampling should use the procedures and sites sampled at Pine Lake in 1992 (Sosiak and Trew 1996).

The volume of inflow from the watershed probably influenced the rate of phosphorus loading and concentration in Pine Lake. Both spring and annual inflow volumes were significantly correlated with maximum TP concentration in the euphotic zone of Pine Lake in the same year ($P \leq 0.036$), but were not otherwise correlated with the water quality variables that were tested for Pine Lake, or a reference lake (Gull Lake). Periods of high runoff may scour more nutrients from the Pine Lake watershed and increase TP concentration in Pine Lake. Phosphorus introduced by periods of high runoff would then cycle between sediments and the water column in subsequent years. Because annual inflow volumes and maximum TP concentrations are correlated, a temporary increase in the rate of phosphorus loading from the watershed, and phytoplankton biomass, may occur in future during years with above average precipitation.

Inflow volume alone does not entirely account for trends in water quality at Pine Lake. TP concentrations were relatively high during 1992 to 1994 (Figure 3), but annual inflow volumes

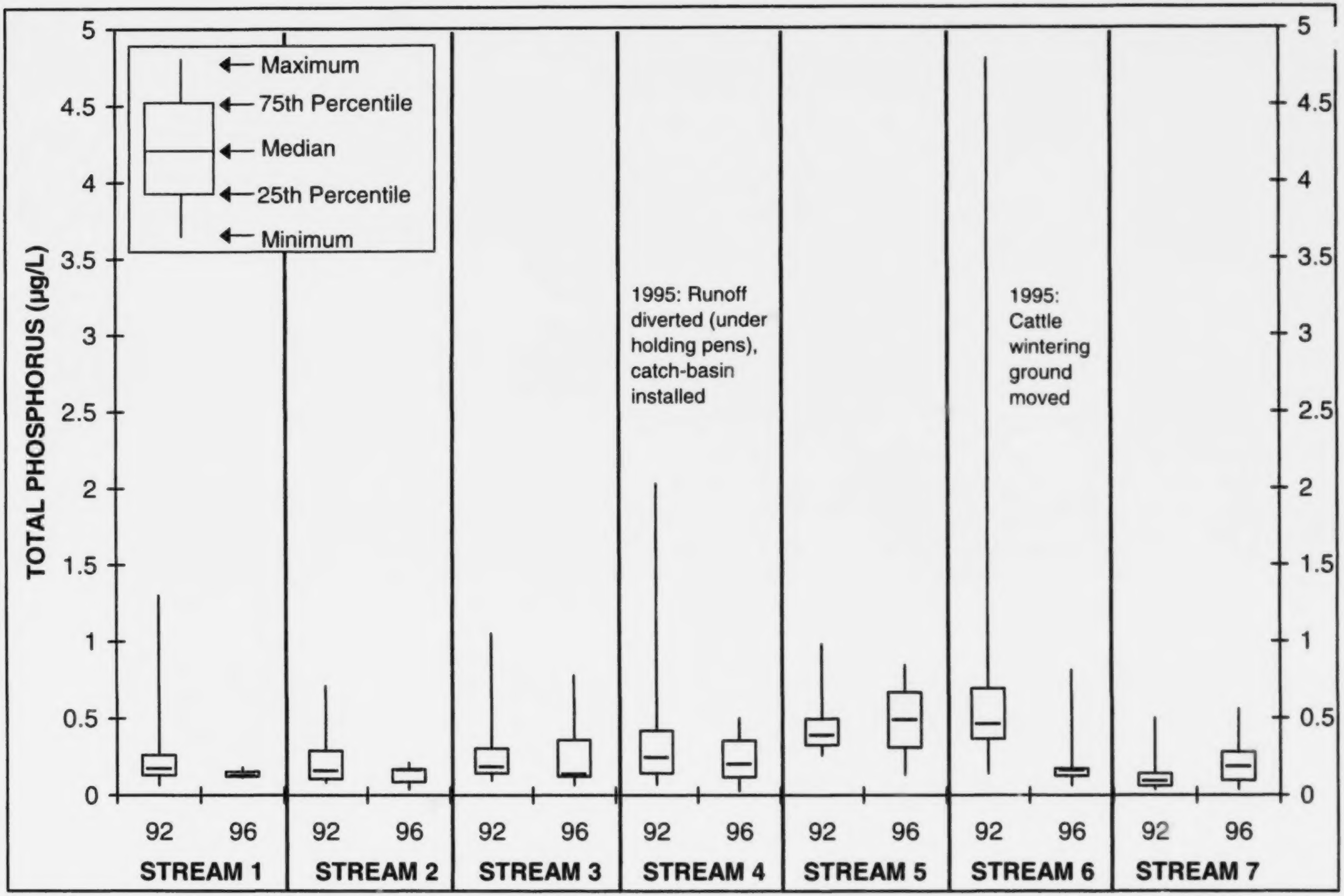


Figure 35 Total phosphorus concentrations in Pine Lake streams, March to October, 1992 and 1996

were average or below average in those years (range 1540 - 3197 dam^3). Furthermore, inflow volumes have not declined consistently during 1996 - 2000 while the TP concentration declined in Pine Lake. Annual inflow volumes were well above average during 1997 and 1999 (Figure 3) during a period of declining TP concentration in Pine Lake (Figure 15).

The mass of TDP exported from Pine Lake to Ghostpine Creek increased greatly during hypolimnetic withdrawal. The mass of TDP entering Ghostpine Creek from Pine Lake was 23 and 93 kg respectively in 1989 and 1992 (Table 5). The mass of TDP exported doubled to 192 kg in 2000, of which 140 kg flowed through the pipeline to Ghostpine Creek, and the remainder passed over the weir. The total TDP mass exported to Ghostpine Creek in 2000 was 99 and 169 kg more than was exported in 1992 and 1989 respectively. To place this increase in perspective, the increased export in 2000 (99 - 169 kg) was similar or greater than the TDP loading from Streams 1, 4 or 6, which contributed the greatest TDP loading to Pine Lake in 1992 (range: 96.0 - 102.3 kg). This increased export was achieved although pipeline flows late in the summer of 2000 were less than half of the flow rates estimated in the design report. Still higher export rates of this highly available form of phosphorus should be possible if pipeline flows can be consistently maintained at the flow rates that the system was designed to achieve.

One factor that contributed to high phosphorus export rates for 2000 was that the phosphorus concentration of water withdrawn by the pipeline was higher than anticipated during planning for this project. The TP concentration of the discharge from the pipeline was on average 85% higher than the deepest TP concentration measured in the south basin, at 10 - 11 m depth. The intake for the hypolimnetic withdrawal system is close to the lake bottom and may withdraw water from the sediment-water interface, which is higher in TP concentration than water even a metre off the bottom. Because the estimates of phosphorus withdrawn from the hypolimnion for 1999 (Table 5) were based on phosphorus profile data, rather than actual measurements of concentration in the discharge, the 1999 estimates could be too low.

Table 5 Phosphorus (kg) export from Pine Lake before and during hypolimnetic withdrawal

	Total Phosphorus			Total Dissolved Phosphorus		
Year	**Creek or Weir**	**Pipe**	**Total**	**Creek or Weir**	**Pipe**	**Total**
Before Hypolimnetic Withdrawal						
1989	34[a]	-	34	23[a]	-	23
1992	263[b]	-	263	93	-	93
During Hypolimnetic Withdrawal						
1999	NA[c]	76	NA	NA	62	NA
2000	82	153	235	52	140	192

[a] Source: TP, Mitchell and Sosiak (1991), TDP estimated using regression
[b] Source: Sosiak and Trew (1996)
[c] Load could not be estimated from available data.

The export of TP from Pine Lake to Ghostpine Creek in 2000 was slightly less than in 1992, but far greater than in 1989 (Table 5). The TP export estimate for 1992 was probably large because euphotic zone TP concentrations were far greater in 1992 than in 2000 (Figure 16). Most of the TP exported in 1992 (65%) was particulate phosphorus, presumably from algal material, which contains forms of phosphorus that are released slowly to the open water (Wetzel 1983). In 2000, only 18% of the TP mass exported was particulate phosphorus.

It was not possible to estimate the mass of phosphorus exported over the weir in 1999 because flow over the weir could not be estimated. An excellent record of weir elevations and stop log operation was kept in 2000 and 2001. Similar records are required for future assessments of flow and phosphorus export from Pine Lake.

3.4 Response of Pine Lake to Reduced Phosphorus Loading

Phosphorus concentration and mass, and algal production in Pine Lake have decreased since the restoration program began. The most plausible explanation for these improvements is that the lake has responded to reduced external phosphorus loading due to watershed projects, and increased phosphorus export from hypolimnetic withdrawal. Other factors such as changes in runoff and natural variability have probably contributed to improved water quality since 1996, but sampling to date (Section 3.3) suggests that more of the improvement can be attributed to the restoration program.

Water quality in Pine Lake has generally responded to the restoration program as predicted by modelling (Mitchell and Sosiak 1991, Sosiak 1997). Average TP measured in the three basins of Pine Lake (mean of medians: 57.6 µg/L, range: 53.4 - 61.2 µg/L) in 2000 was close to the most conservative modelling prediction for TP concentration (57.2 µg/L, Sosiak 1997) following the completion of watershed restoration and in-lake treatment. The actual chlorophyll *a* measurements in 2000 (range of medians: 7.5 - 11.1 µg/L) and Secchi depth (range: 2.7 - 3.4 m) in 2000 exceeded the optimistic predictions from Scenario 6 (Sosiak 1997, lake wide averages, chlorophyll *a*: 13.4 µg/L, Secchi: 2.3), which was considered a reasonable long-term objective for the restoration program. Median chlorophyll *a* in the three basins declined by 76 to 81% between 1992 and 2000, compared to a 72% decline over all basins that was predicted by modelling (Sosiak 1997). Scenario 6 was based on the assumption that internal phosphorus loading could be reduced by 65%, and that TP loading from all streams could be reduced to levels found in Stream 7, which was considered to have the lowest phosphorus level that can be achieved in the Pine Lake basin. Similarly, Mitchell and Sosiak (1991) predicted that the summer average chlorophyll *a* in Pine Lake could be reduced to 7.6 µg/L after nutrient reduction, which is similar to the concentration that was measured in the north basin in 2000.

The modelling presented in Sosiak (1997) predicted that algal blooms would continue to occur in Pine Lake following a reduction in external and internal phosphorus loading. Although a substantial reduction in algal biomass was predicted in Scenario 6, this modelling predicted that algal blooms that represent severe nuisance conditions (>30 µg/L, Walker 1996) would still occasionally occur following a substantial reduction in internal and external phosphorus loading. Although median levels of chlorophyll *a* were relatively low in 2000, concentrations up to

49 µg/L occurred in the middle basin for a brief period in late August 2000. The sampling intervals each year when chlorophyll *a* exceeded the 30-µg/L criterion for nuisance conditions during 1999 and 2000 were only 8.0 and 7.7% of the total sampling period respectively. Nuisance algal blooms will likely continue to occur in Pine Lake during the late summer, but these blooms should decrease in severity and frequency if phosphorus levels continue to decline.

3.5 Impacts of Hypolimnetic Withdrawal on Ghostpine Creek

More flow occurred in Ghostpine Creek downstream from Pine Lake during the summer during hypolimnetic withdrawal than occurred before weir installation and impoundment. During hypolimnetic withdrawal, the pipeline alone discharged 0.024 to 0.216 m^3/s (Figure 4) to Ghostpine Creek throughout the summers of 1999 and 2000. In addition mean monthly flow over the weir ranged between 0.243 in June and 0.008 m^3/s in August 2000. Flow over the weir in 1999 could not be estimated, because details on stop log operation were not recorded that year. However, AENV field records note that there was considerable flow over the weir following heavy rain in July 1999. In contrast, there was no measurable flow in Ghostpine Creek at the County Bridge, near the Pine Lake outflow, after July 11, 1989 and after August 11, 1992. There is no flow gauge on Ghostpine Creek near Pine Lake. However, Ames (1992) modelled inflow and outflow for the period 1981 to 1990, and estimated that no outflow occurred during August in three of the 10 years, and flows were generally low during the remaining years in August.

The historic site at the County Bridge on Ghostpine Creek (site AB05CE0570) is upstream from the discharge of the hypolimnetic withdrawal system (Figure 2a). Accordingly a new site on Ghostpine Creek about 700 m downstream from the stilling basin at Range Road 245 (AB05CE2140) was first sampled in 1998. This site is also sampled by the Pine Lake Restoration Society to meet the requirements of the Interim License for the system. Data from these two sampling sites have been merged for presentation in Figures 36 to 40.

Median levels of TP, TDP, ammonia, and nitrite+nitrate (Figures 36 and 37) in the discharge from the hypolimnetic withdrawal system exceeded euphotic zone concentrations in 2000 (Appendix I). However, during hypolimnetic withdrawal in 1999 and 2000, the median TP concentration at the three sites on Ghostpine Creek was within the historic range of concentration, or lower (Figure 36). In spite of increased TDP loading from hypolimnetic withdrawal, downstream TP concentrations have not increased compared to historic levels because TP concentrations in Pine Lake have declined since 1996.

In contrast, median TDP concentration was higher during hypolimnetic withdrawal at the first site downstream of the system discharge at Range Road 245 than in 1989 and 1992 (Figure 36). Both median TP and TDP were much higher at sites further downstream on Ghostpine Creek (Highway 585 and 27), than at Range Road 245, before and during hypolimnetic withdrawal. Furthermore, median TP concentrations at all sites along Ghostpine Creek were generally above the ASWQ guideline (0.05 mg/L) before and during hypolimnetic withdrawal (Figure 36).

No TDP measurements were available prior to hypolimnetic withdrawal at Highway 585 and 27, and fewer measurements of all variables were available in 1986 ($N = 4$) and 1998 ($N = 2$) than in

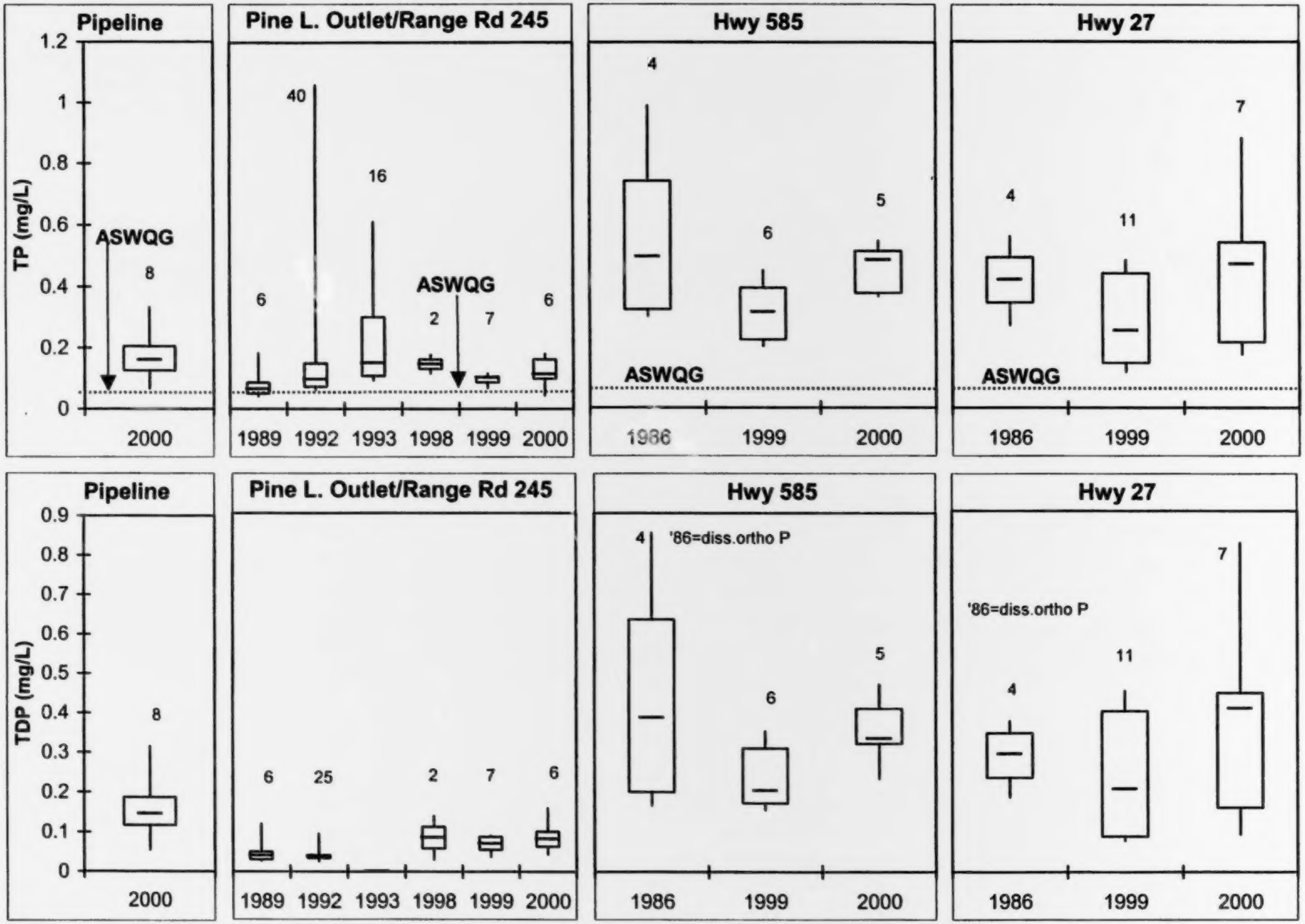


Figure 36 Concentration of total and dissolved phosphorus at three sites on Ghostpine Creek and in the hypolimnetic pipeline discharge

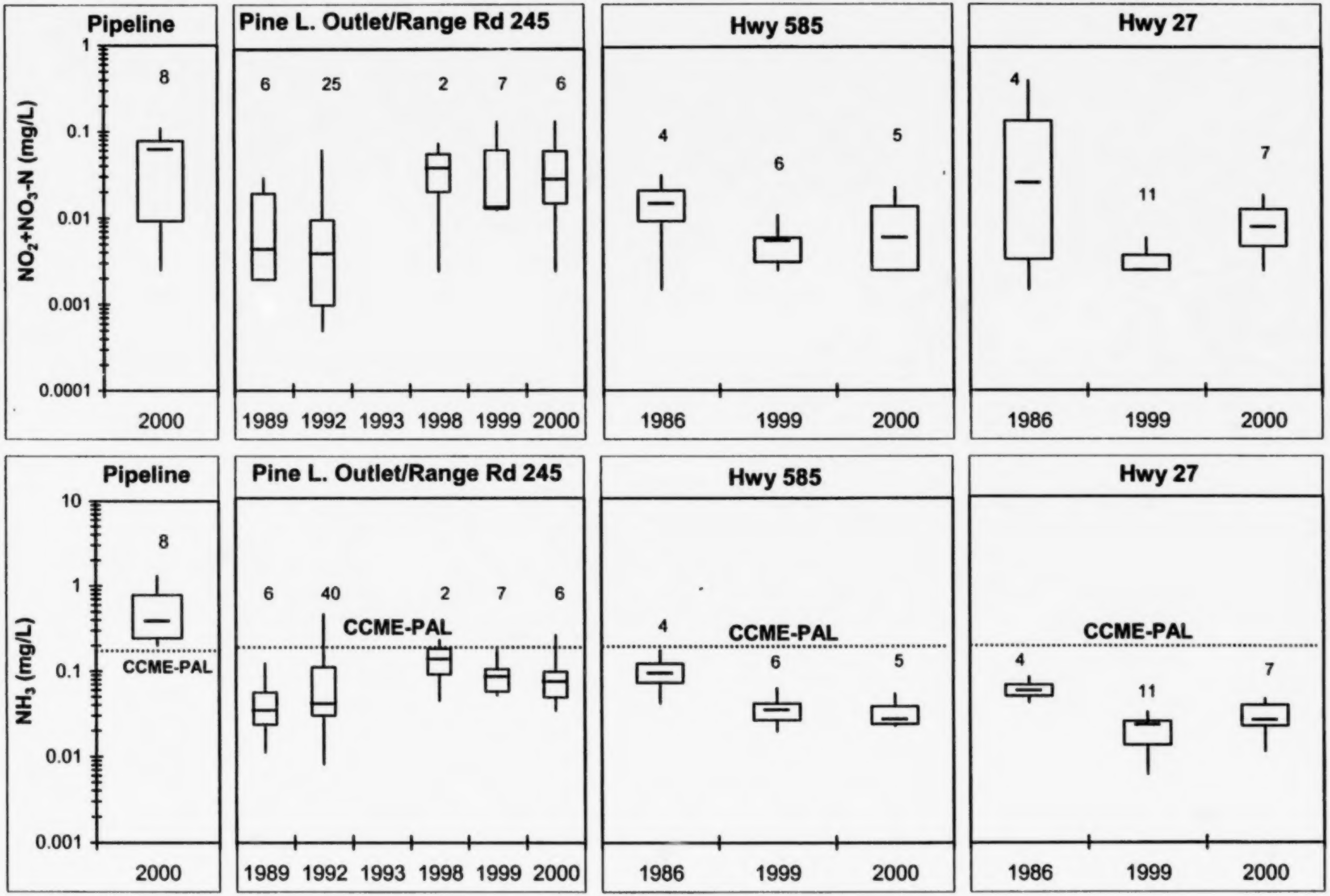


Figure 37 Concentration of nitrite+nitrate nitrogen and ammonia nitrogen at three sites on Ghostpine Creek and in the hypolimnetic pipe discharge

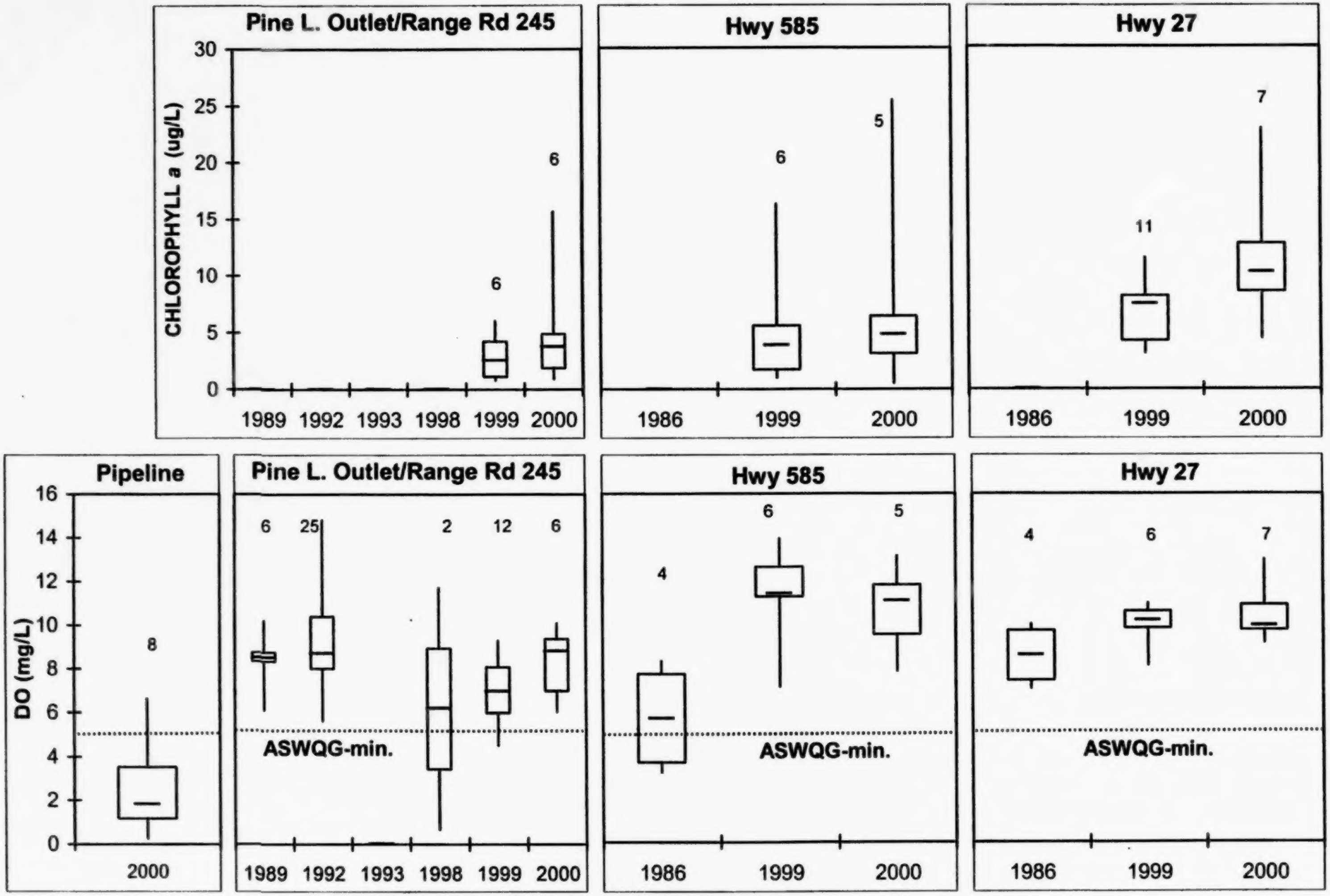


Figure 38 Concentration of chlorophyll *a* and dissolved oxygen at three sites on Ghostpine Creek and in the hypolimnetic pipe discharge

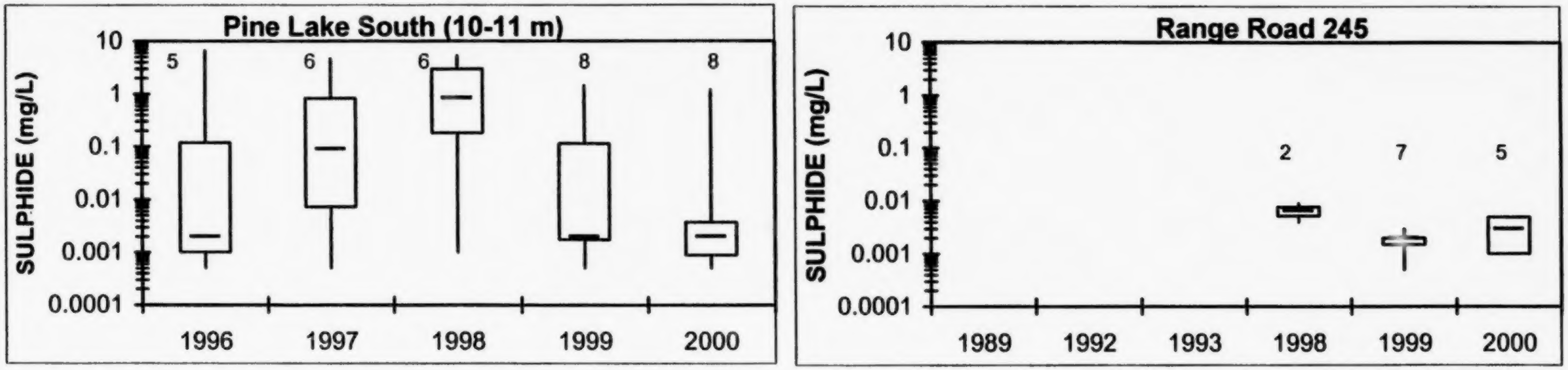


Figure 39 Concentration of dissolved sulphide in Pine Lake south basin and Ghostpine Creek at Range Road 245

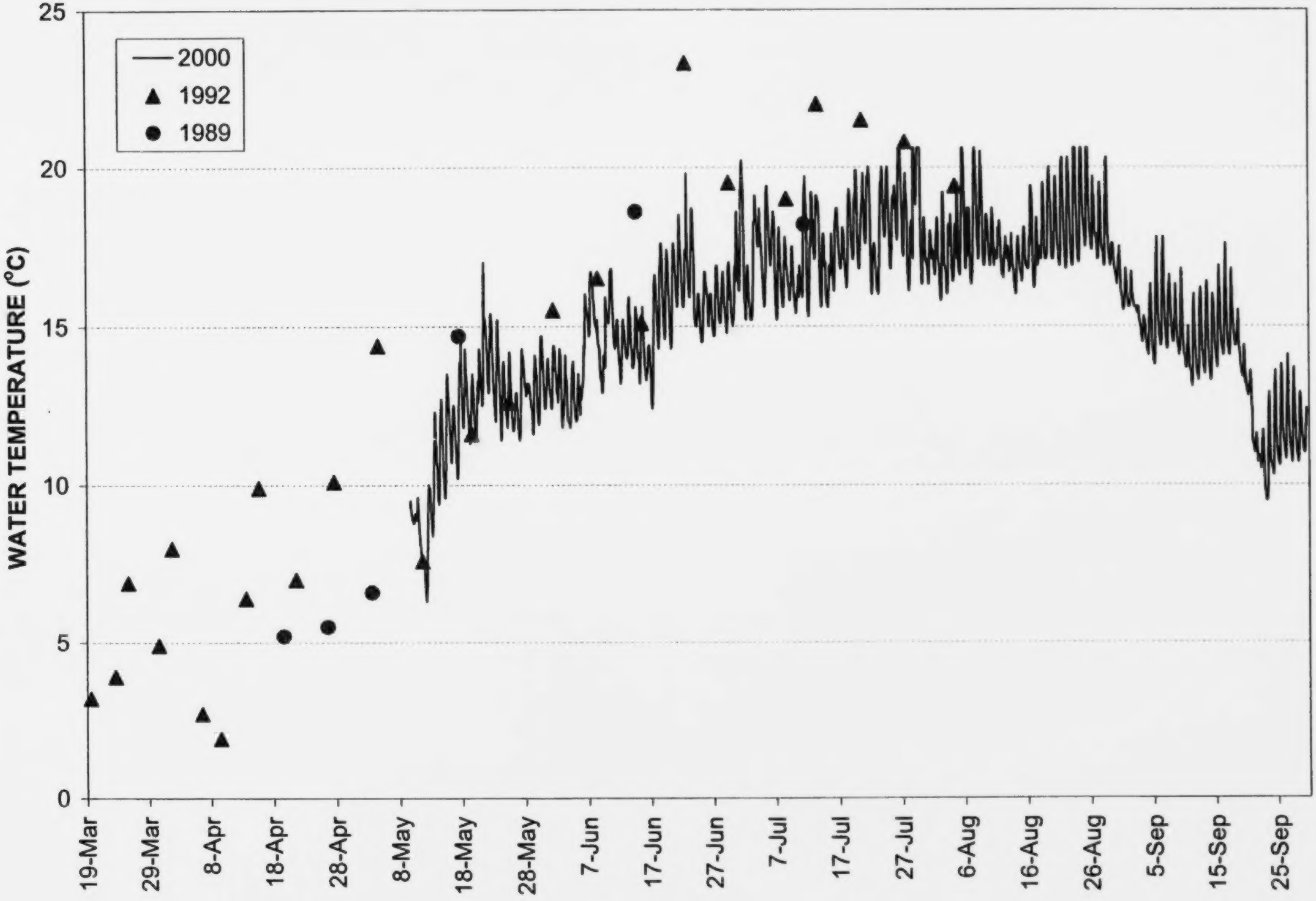


Figure 40 Water temperature in Ghostpine Creek near the Pine Lake outflow before (1989, 1992) and after (2000) the installation of the hypolimnetic withdrawal system

other years (N = 6 to 40). Instead of TDP, soluble reactive phosphorus (SRP) results from 1986 have been plotted in Figure 36. These high SRP results suggest that high levels of dissolved phosphorus occurred at these sites even before hypolimnetic withdrawal.

Like TDP, median nitrite+nitrate and ammonia concentrations were higher during hypolimnetic withdrawal than in 1989 and 1992 at Range Road 245, but within the historic range, or lower, during hypolimnetic withdrawal at sites further downstream (Figure 37). Ammonia concentrations in the discharge from the hypolimnetic withdrawal (Figure 37) were over CEQ guidelines (CCME 2000) on three sampling dates late in the summer of 2000, and on one occasion at the Pine Lake outflow in 1992, but were otherwise below guidelines at other sites. To illustrate the approximate range of concentration relative to guidelines, the most stringent guideline for ammonia (0.137 mg/L) for the pH and water temperature on any sampling date, at any site, has been plotted in Figure 36. However, the CEQ guidelines for ammonia vary with the actual pH and water temperature that occur on a given date.

The impact of increased nutrient discharge on aquatic plants in Ghostpine Creek cannot be evaluated with the available data. There are no historic phytoplankton (sestonic) or periphytic chlorophyll *a* data from Ghostpine Creek that can be used to evaluate impacts on aquatic plant growth prior to hypolimnetic withdrawal. However, during at least the summer of 2000 a floating mat that appeared to be filamentous green algae developed in the stilling basin. In spite of the high phosphorus levels in Ghostpine Creek (Figure 36), phytoplankton chlorophyll *a* levels were relatively low on most sampling trips in 1999 and 2000 (Figure 38). Median chlorophyll *a* at all sites ranged from 2.5 to 10.2 μg/L (maximum per site ≤ 25.4 μg/L), which suggests oligotrophic to mesotrophic conditions, using the sestonic boundaries (10, 30 μg/L) proposed by Dodds et al. (1998). Turbidity and suspended sediments are relatively high at Ghostpine Creek sites at Highway 585 and 27 (range of medians: turbidity, 8.3 - 40 NTU; NFR, 7.0 - 29.5 mg/L) (Appendix I) and creek water is highly coloured (range: 59 - 250 TCU). High colour and turbidity probably reduce light penetration, and may inhibit algal growth in lower Ghostpine Creek.

Dissolved oxygen in the discharge from the pipeline was below the ASWQ guideline (5 mg/L) from at least June 13 to August 21, 2000 (Figure 38). As expected, the discharge became anoxic (< 1 mg/L) from July 26 to August 21 when the south basin hypolimnion became anoxic (Figure 10). Although the median dissolved oxygen concentration at Range Road 245 in 1999 was lower than in 1989 and 1992, oxygen concentrations were similar to historic data in 2000, and generally above the guideline both years. Median dissolved oxygen concentrations at Highway 585 and 27 during hypolimnetic withdrawal were above the guideline, and were higher than in 1986. These higher oxygen concentrations probably reflect higher flows during 1999 and 2000. In spite of the anoxic discharge during hypolimnetic withdrawal, regular oxygen measurements during the day provided little evidence of significant oxygen depletion in Ghostpine Creek downstream from Pine Lake. However, lower oxygen concentrations could occur in Ghostpine Creek closer to the stilling basin, or at night due the additional oxygen demand caused by plant respiration.

The median concentration of dissolved sulphide in Ghostpine Creek at the first site downstream from the discharge of hypolimnetic withdrawal (Range Road 245) has declined since 1998. This decline in sulphide probably reflects an increase in dissolved oxygen in the hypolimnion of the south basin of Pine Lake over the same time period (Section 3.2.2). As noted in Section 3.2.2, there has been little evidence to date that the changes in dissolved oxygen in the south basin during the open water season since 1998 have been caused by hypolimnetic withdrawal. All the sulphide measurements in Ghostpine Creek at Range Road 245 were below the USEPA guideline (2 µg/L as hydrogen sulphide)(Figure 39) during 1998 to 2000. Odour measurements and field notes from 1999 and 2000 provided little evidence of odours associated with sulphide at Range Road 245 (median threshold odour number ≤ 1, Appendix I). Only two sulphide measurements were available from Ghostpine Creek before hypolimnetic withdrawal, during sporadic outflows from Pine Lake in 1998 (Figure 39). If dissolved oxygen concentrations continue to decrease in the south basin, further declines in sulphide in the south basin and discharge from the hypolimnetic withdrawal can be anticipated.

Water temperatures in Ghostpine Creek downstream from the County Bridge were somewhat cooler during hypolimnetic withdrawal in June and July 2000 than in previous years, but there was little apparent change in water temperature during May (Figure 40). Water temperatures recorded hourly in 2000 were on average 3.0°C cooler in June, and 3.2°C cooler in July, than weekly daytime measurements in 1992.

Various factors other than hypolimnetic withdrawal probably contributed to the apparent difference in water temperature. The measurement frequency and sampling methods were different in the two years, and there was less flow in 1992, when flow in Ghostpine Creek stopped completely at the Pine Lake outlet by August 11. However, water temperatures are typically lower than prior to impoundment in the tailwater of a reservoir that discharges from the hypolimnion (Hynes 1970), and reduced temperatures in Ghostpine Creek during hypolimnetic withdrawal would be expected. Since thermal stratification has been moderately weak in Pine Lake, and bottom temperatures have been relatively warm most years (Section 3.2.1), one would not expect a large decline in tailwater temperatures in Ghostpine Creek due to hypolimnetic withdrawal.

Median iron concentrations were slightly higher in Ghostpine Creek at Range Road 245 and Highway 585 during hypolimnetic withdrawal, compared to historic data at these sites, but lower at Highway 27 (Figure 41). Single iron measurements exceeded the CEQ guideline at Range Road 245 during the spring before hypolimnetic withdrawal, and single iron and aluminum measurements exceeded guidelines in 2000 (Figure 41). Iron often exceeded the CEQ guideline at Highway 585 and 27 in 1986, and both iron and aluminum frequently exceeded the CEQ guidelines at these sites during hypolimnetic withdrawal. Since iron and aluminum levels were much higher at these sites than at Range Road 245, these higher metal concentrations must be caused by loading to Ghostpine Creek downstream from Range Road 245. No aluminum measurements were available for Ghostpine Creek prior to hypolimnetic withdrawal.

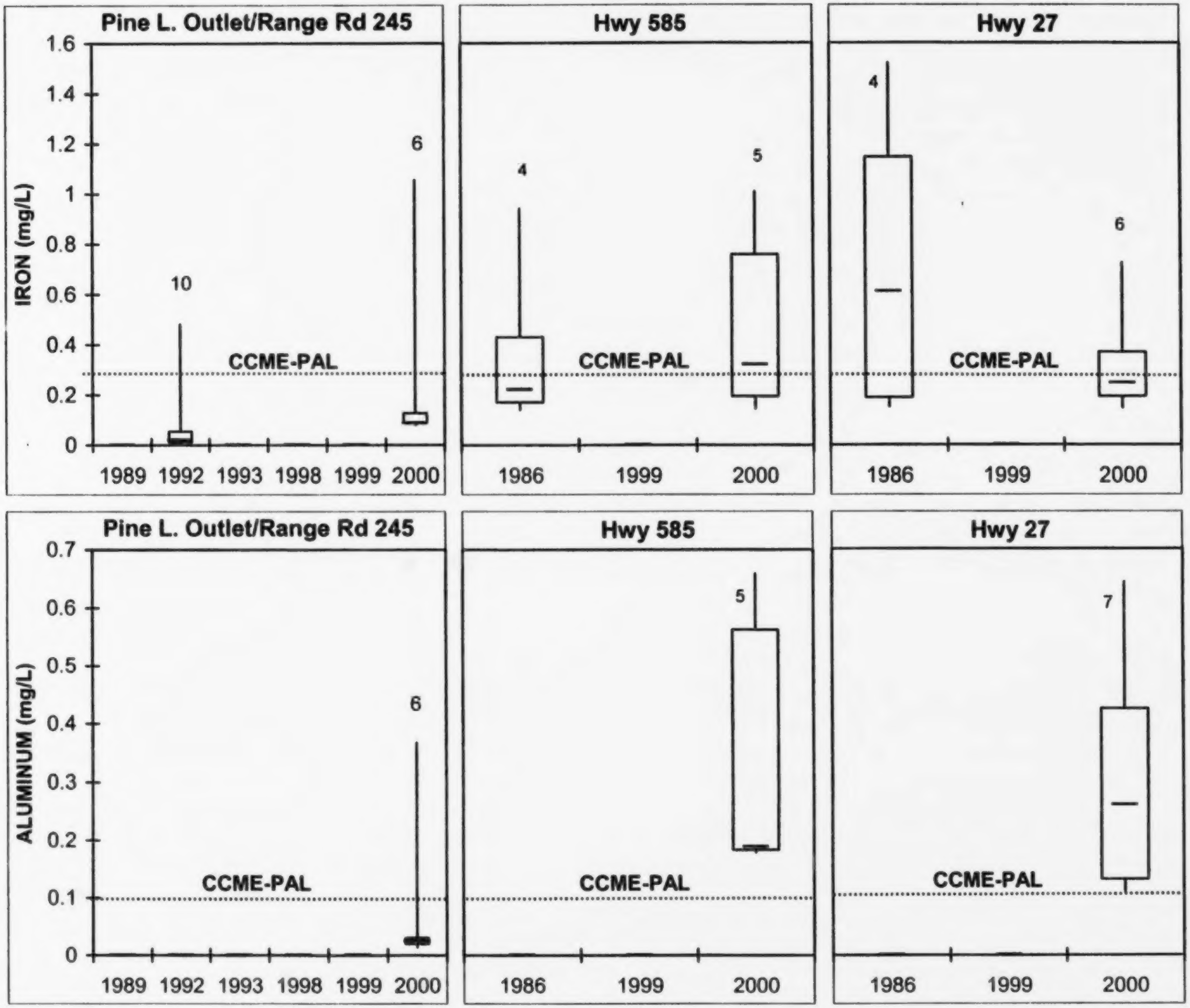


Figure 41 **Concentration of iron and aluminium at three sites on Ghostpine Creek**

4.0 CONCLUSIONS

4.1 Restoration Program

1. The Pine Lake Restoration Program demonstrates that communities can effectively plan and implement a watershed and lake stewardship program in partnership with government.

2. Sampling to date suggests that much of the improvement in water quality in Pine Lake can be attributed to the restoration program. Further monitoring of key water quality variables will be required to conclusively demonstrate that the large decline in chlorophyll *a*, and other variables, is mainly due to the restoration program and not merely natural variation.

4.2 Physical, Chemical and Biological Characteristics of Pine Lake and Ghostpine Creek

1. Thermal stratification occurred in the middle and south basins each year, while the shallow north basin was often nearly isothermal. Stratification influenced water temperatures in the hypolimnion, and probably influenced sediment phosphorus release some years. Stratification was moderately weak, and weather-induced mixing sometimes occurred. There was little evidence that hypolimnetic withdrawal adversely affected thermal stratification or caused premature mixing of the lake during the first two years of operation.

2. There was sufficient thermal stratification each summer that near anoxia (< 1 mg/L) developed in the profundal waters of all three basins. The vertical extent and duration of anoxia was greatest in 1995, 1997 and 1998. Although anoxia and sulphide levels in profundal waters have since declined, there has been little evidence to date that hypolimnetic withdrawal alone has reduced anoxia in profundal waters during the open water season. However, dissolved oxygen concentrations have improved during the winter since the completion of the restoration program in at least the middle basin of Pine Lake.

3. Lake levels exceeded the preferred range for recreation and target levels for at least two weeks in 1999 following unusually heavy rain. Levels were thereafter within an acceptable range for recreation for the remainder of the season, and for most of 2000.

4. Appreciable sediment phosphorus release occurred nearly every summer in Pine Lake. This release was interrupted by weather-induced lake mixing in at least 1992 and 1999, and relatively little phosphorus release was detected by sampling in 1997.

5. TP and chlorophyll *a* concentrations in the euphotic zone of Pine Lake increased significantly from near natural conditions (boundary between mesotrophic and

eutrophic states) in 1978 and 1979, to peak concentrations during 1992 to 1996. The reasons for this increase are not known.

6. Unusually low levels of TP and chlorophyll *a* in Pine Lake in 1995 could be due to low runoff and low external phosphorus loading, and less movement of phosphorus from the hypolimnion to the euphotic zone.

7. TP concentrations and mass, and chlorophyll *a* in the three basins of Pine Lake have declined significantly and Secchi depth has increased following the restoration program. However, nuisance algal blooms have occurred, and will likely continue to occur, during the late summer as predicted by modelling. Such algal blooms should decrease in severity and frequency if phosphorus levels continue to decline.

8. Although median TP in Pine Lake in 2000 was still well above concentrations here considered indicative of natural conditions (mesotrophic-eutrophic boundary), chlorophyll *a* and Secchi depth approached this boundary. The latter indicators suggest that algal production in Pine Lake in 2000 approached levels thought to occur naturally.

9. Flow from the hypolimnetic withdrawal system was about half the flow predicted in the project design report throughout 1999, and the latter part of the summer of 2000. Beaver dams that impounded the pipe outlet, and reduced the effective head of the system, and floating of the pipe near the weir probably caused reduced flows.

10. Although the flow from hypolimnetic withdrawal was less than the designed rate, 99 - 169 kg more TDP was exported to Ghostpine Creek during hypolimnetic withdrawal in 2000, than was exported in 1989 and 1992.

11. The biggest decline in TP mass occurred during hypolimnetic withdrawal, and probably reflects phosphorus export by hypolimnetic withdrawal, decreased tributary loading, and loss over the weir to Ghostpine Creek. The reduction in TP mass that can be attributed to each change cannot be estimated from the available data, but at least 29% was due to hypolimnetic withdrawal.

12. Water withdrawal by the Whispering Pine Golf and Country Club Resort during the period of maximum internal loading would probably increase TP removal. However, water withdrawal by the resort must be coordinated with hypolimnetic withdrawal to maintain the target lake levels.

13. Peak TN concentrations occurred in most basins of Pine Lake in 1992, and thereafter fluctuated at lower levels. Nitrogen concentrations did not decline to the same extent as phosphorus following the restoration program.

14. This analysis found little statistically significant variation between basins in the concentration of TP, chlorophyll *a*, or Secchi depth in the 15 years sampled during 1978 - 2000. Accordingly there is little evidence to date that one basin in the lake is

more affected by the restoration program than other basins. However, more spatial variation could occur in future during hypolimnetic withdrawal.

15. Discharge from hypolimnetic withdrawal has increased the concentration of some dissolved constituents and flow, and lowered water temperatures and dissolved oxygen just downstream from the point of discharge. Results to date do not provide evidence of significant adverse aquatic impact on Ghostpine Creek.

16. Dissolved sulphide levels have declined in Pine Lake and in Ghostpine Creek downstream from the discharge of the hypolimnetic withdrawal since 1998. A further decline in sulphide concentration can be expected if dissolved oxygen levels improve in Pine Lake during the open water season.

17. Factors such as differences in runoff between years and natural variability have probably contributed to improved water quality since 1996. However, there is no evidence to date of a general decline in TP concentration in other Alberta lakes since 1996, due to natural factors, that could explain the decline in TP at Pine Lake. A temporary increase in phosphorus loading and phytoplankton biomass may occur in future during years with above average precipitation.

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Appendix 1 Median values for samples collected during the open-water season from Pine Lake, 1992-2000 and Ghostpine Creek, 1986-2000

Appendix 1a Median values for euphotic zone composite samples collected during the open-water season from Pine Lake, 1992-2000

VARIABLE	UNITS	SOUTH BASIN								
		92	93	94	95	96	97	98	99	2000
No. Samples:		18	9	8	8	7	5	6	11	11
TP-Maxxam/ARCV	mg/L	0.083	0.087	0.077	0.069	0.090	0.107	0.081	0.067	0.052
TP-McIntyre	mg/L	0.0888	0.1132	0.1011	0.0719	0.0953	0.0890	0.0787	0.0683	0.0534
TDP-Maxxam/ARCV	mg/L	0.032	0.058	0.040	0.037	0.053	0.030	0.059	0.033	0.032
TDP-McIntyre	mg/L	0.0351	0.0380	0.0420	0.0370	0.0533	0.0332	0.0591	0.0339	0.0328
PO$_4$, diss. Ortho	mg/L	0.002	0.018	0.009	0.005	--	0.017	0.031	0.005	0.009
P, part.	mg/L	--	--	--	--	0.021	0.022	0.021	0.038	0.020
TKN	mg/L	2.05	1.78	2.15	1.60	1.55	1.90	1.74	1.62	1.58
NH$_3$, tot.	mg/L	--	--	--	--	0.120	--	--	--	--
NH$_3$, diss.	mg/L	0.123	0.124	0.182	0.088	0.404	0.193	0.155	0.102	0.082
NO$_2$+NO$_3$-N, diss.	mg/L	0.026	0.006	0.006	0.007	0.015	0.011	0.013	0.008	0.012
Nitrite, diss.	mg/L	0.007	0.002	0.003	0.003	0.002	0.002	0.004	0.003	0.001
TN	mg/L	2.103	1.798	2.149	1.676	1.573	1.915	1.760	1.638	1.669
N, part.	mg/L	--	0.49	0.40	0.17	0.15	0.24	--	--	--
Silica	mg/L	3.0	2.2	1.8	2.8	6.2	3.0	2.3	4.1	4.5
TOC	mg/L	--	--	--	--	18.4	--	--	--	--
TIC	mg/L	--	--	--	--	75.0	--	--	--	--
DOC	mg/L	18.1	18.5	18.1	18.0	17.8	17.7	18.6	16.3	16.2
DIC	mg/L	71.0	66.8	70.8	72.6	73.7	67.1	73.7	--	--
C, part.	mg/L	2.94	2.77	2.24	1.18	0.30	1.45	0.98	--	--
COD	mg/L	54	54	54	46	49	54	52	--	--
CHL a	mg/m3	45.6	34.5	28.2	14.1	13.2	22.6	9.0	14.9	11.1
Phenols	mg/L	0.012	0.009	0.008	0.010	0.001	0.010	0.009	--	--
Conductance	uSie/cm	704	692	696	695	708	683	718	712	--
TDS, calc.	mg/L	418	410	416	422	432	400	430	424	432
TDS	mg/L	472	473	484	473	486	468	493	482	493
NFR	mg/L	6	6	4	2	2	4	2	3	2
FR	mg/L	--	--	--	--	420	--	--	--	--
TR	mg/L	478	480	488	474	488	474	494	486	494
Turbidity	NTU	4.80	7.50	3.80	1.80	3.00	2.80	1.42	0.89	1.60
Total Alkalinity	mg/L	305	305	306	313	310	306	319	313	318
PP Alkalinity	mg/L	--	--	--	--	9.4	13.0	9.5	8.0	11.0
pH	units	8.60	8.70	8.59	8.63	8.52	8.67	8.55	8.50	8.63
Hardness	mg/L	167	166	165	168	170	152	161	163	170

VARIABLE	UNITS	SOUTH BASIN								
		92	93	94	95	96	97	98	99	2000
Sodium, diss.	mg/L	99	95	98	100	105	98	107	102	106
Calcium, diss.	mg/L	24.0	27.0	24.5	26.0	27.6	23.2	24.8	27.2	28.7
Magnesium, diss.	mg/L	25.0	24.0	25.0	25.0	24.4	22.9	24.0	23.3	23.2
Potassium, diss.	mg/L	9.5	9.3	10.2	9.9	10.5	10.2	10.3	9.9	9.6
Chloride, diss.	mg/L	7.0	7.2	7.9	8.1	8.1	8.2	8.6	9.6	8.7
Sulphate, diss.	mg/L	68	62	64	66	63	59	64	65	68
Fluoride, diss.	mg/L	0.23	0.23	0.25	0.25	0.27	0.24	0.25	0.25	--
Bicarbonate	mg/L	362	358	362	355	353	342	368	362	359
Carbonate, diss.	mg/L	12	14	13	14	11	15	12	9	14
Secchi Depth	m	1.3	1.5	2.7	3.0	2.5	2.0	2.9	2.4	3.4
Al, tot.	mg/L	--	<0.005	<0.005	<0.005	0.020	0.040	0.016	0.015	0.013
Al, ext.	mg/L	0.005	--	--	--	--	--	--	--	--
As, tot.	mg/L	0.0006	0.0006	0.0006	0.0006	0.0006	0.0011	0.0011	--	0.00109
As, diss.	mg/L	--	--	--	0.0006	--	--	--	--	--
Ba, tot.	mg/L	0.058	0.056	0.055	0.053	0.060	0.054	0.0596	--	0.0639
Be, tot.	mg/L	--	--	--	--	--	--	<0.00004	--	<0.00004
Be, diss.	mg/L	<0.001	<0.001	<0.001	<0.001	--	--	--	--	--
Cd, tot.	mg/L	0.002	<0.001	<0.001	<0.001	<0.0002	<0.001	<0.00002	--	<0.00002
Cr, tot.	mg/L	0.003	<0.001	<0.001	<0.001	0.008	<0.001	0.00033	0.0003	0.00013
Co, tot.	mg/L	0.001	0.0005	<0.001	<0.001	<0.001	--	0.00008	--	0.00009
Cu, tot.	mg/L	0.002	<0.001	<0.001	<0.001	0.0008	<0.001	0.000445	--	0.0003
Fe, tot.	mg/L	0.033	0.028	0.019	0.025	0.023	0.043	0.013	0.032	0.013
Fe, ext.	mg/L	0.005	--	--	--	--	--	--	0.011	--
Pb, tot.	mg/L	--	--	--	--	0.0008	<0.005	0.000191	--	0.000094
Pb, ext.	mg/L	<0.002	<0.002	<0.002	<0.002	--	--	--	--	--
Mn, tot.	mg/L	0.008	0.014	0.015	0.011	0.013	0.006	0.0161	0.0133	0.00925
Hg, tot.	ug/L	<0.1	<0.1	<0.1	<0.04	<0.05	<0.04	<0.04	--	<0.005
Mo, tot.	mg/L	0.002	<0.001	<0.001	<0.001	--	--	0.00055	--	0.00062
Ni, tot.	mg/L	0.004	<0.001	<0.001	0.001	0.0034	0.001	0.0002	0.00029	0.00087
Se, tot.	mg/L	<0.0001	0.0001	<0.0001	--	--	--	0.0003	--	0.0003
Va, tot.	mg/L	0.003	<0.002	<0.002	<0.002	--	--	0.00038	--	0.00043
Zn, tot.	mg/L	0.002	0.002	<0.001	<0.001	0.01	<0.001	0.00118	--	0.00116

-- = not analyzed

Appendix 1a Median values for euphotic zone composite samples collected during the open-water season from Pine Lake, 1992-2000

VARIABLE	UNITS	SOUTH BASIN								
		92	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**2000**
No. Samples:		18	9	8	8	7	5	6	11	11
TP-Maxxam/ARCV	**mg/L**	**0.083**	**0.087**	**0.077**	**0.069**	**0.090**	**0.107**	**0.081**	**0.067**	**0.052**
TP-McIntyre	mg/L	0.0888	0.1132	0.1011	0.0719	0.0953	0.0890	0.0787	0.0683	0.0534
TDP-Maxxam/ARCV	**mg/L**	**0.032**	**0.058**	**0.040**	**0.037**	**0.053**	**0.030**	**0.059**	**0.033**	**0.032**
TDP-McIntyre	mg/L	0.0351	0.0380	0.0420	0.0370	0.0533	0.0332	0.0591	0.0339	0.0328
PO_4, diss. Ortho	**mg/L**	**0.002**	**0.018**	**0.009**	**0.005**	**–**	**0.017**	**0.031**	**0.005**	**0.009**
P, part.	mg/L	--	--	--	--	0.021	0.022	0.021	0.038	0.020
TKN	**mg/L**	**2.05**	**1.78**	**2.15**	**1.60**	**1.55**	**1.90**	**1.74**	**1.62**	**1.58**
NH_3, tot.	mg/L	--	--	--	--	0.120	--	--	--	--
NH_3, diss.	**mg/L**	**0.123**	**0.124**	**0.182**	**0.088**	**0.404**	**0.193**	**0.155**	**0.102**	**0.082**
NO_2+NO_3-N, diss.	mg/L	0.026	0.006	0.006	0.007	0.015	0.011	0.013	0.008	0.012
Nitrite, diss.	**mg/L**	**0.007**	**0.002**	**0.003**	**0.003**	**0.002**	**0.002**	**0.004**	**0.003**	**0.001**
TN	mg/L	2.103	1.798	2.149	1.676	1.573	1.915	1.760	1.638	1.669
N, part.	**mg/L**	**–**	**0.49**	**0.40**	**0.17**	**0.15**	**0.24**	**–**	**–**	**–**
Silica	mg/L	3.0	2.2	1.8	2.8	6.2	3.0	2.3	4.1	4.5
TOC	**mg/L**	**–**	**–**	**–**	**–**	**18.4**	**–**	**–**	**–**	**–**
TIC	mg/L	--	--	--	--	75.0	--	--	--	--
DOC	**mg/L**	**18.1**	**18.5**	**18.1**	**18.0**	**17.8**	**17.7**	**18.6**	**16.3**	**16.2**
DIC	mg/L	71.0	66.8	70.8	72.6	73.7	67.1	73.7	--	--
C, part.	**mg/L**	**2.94**	**2.77**	**2.24**	**1.18**	**0.30**	**1.45**	**0.98**	**–**	**–**
COD	mg/L	54	54	54	46	49	54	52	--	--
CHL a	**mg/m3**	**45.6**	**34.5**	**28.2**	**14.1**	**13.2**	**22.6**	**9.0**	**14.9**	**11.1**
Phenols	mg/L	0.012	0.009	0.008	0.010	0.001	0.010	0.009	--	--
Conductance	**uSie/cm**	**704**	**692**	**696**	**695**	**708**	**683**	**718**	**712**	**–**
TDS, calc.	mg/L	418	410	416	422	432	400	430	424	432
TDS	**mg/L**	**472**	**473**	**484**	**473**	**486**	**468**	**493**	**482**	**493**
NFR	mg/L	6	6	4	2	2	4	2	3	2
FR	**mg/L**	**–**	**–**	**–**	**–**	**420**	**–**	**–**	**–**	**–**
TR	mg/L	478	480	488	474	488	474	494	486	494
Turbidity	**NTU**	**4.80**	**7.50**	**3.80**	**1.80**	**3.00**	**2.80**	**1.42**	**0.89**	**1.60**
Total Alkalinity	mg/L	305	305	306	313	310	306	319	313	318
PP Alkalinity	**mg/L**	**–**	**–**	**–**	**--**	**9.4**	**13.0**	**9.5**	**8.0**	**11.0**
pH	units	8.60	8.70	8.59	8.63	8.52	8.67	8.55	8.50	8.63
Hardness	**mg/L**	**167**	**166**	**165**	**168**	**170**	**152**	**161**	**163**	**170**

VARIABLE	UNITS	SOUTH BASIN								
		92	93	94	95	96	97	98	99	2000
Sodium, diss.	mg/L	99	95	98	100	105	98	107	102	106
Calcium, diss.	mg/L	24.0	27.0	24.5	26.0	27.6	23.2	24.8	27.2	28.7
Magnesium, diss.	mg/L	25.0	24.0	25.0	25.0	24.4	22.9	24.0	23.3	23.2
Potassium, diss.	mg/L	9.5	9.3	10.2	9.9	10.5	10.2	10.3	9.9	9.6
Chloride, diss.	mg/L	7.0	7.2	7.9	8.1	8.1	8.2	8.6	9.6	8.7
Sulphate, diss.	mg/L	68	62	64	66	63	59	64	65	68
Fluoride, diss.	mg/L	0.23	0.23	0.25	0.25	0.27	0.24	0.25	0.25	--
Bicarbonate	mg/L	362	358	362	355	353	342	368	362	359
Carbonate, diss.	mg/L	12	14	13	14	11	15	12	9	14
Secchi Depth	m	1.3	1.5	2.7	3.0	2.5	2.0	2.9	2.4	3.4
Al, tot.	mg/L	--	<0.005	<0.005	<0.005	0.020	0.040	0.016	0.015	0.013
Al, ext.	mg/L	0.005	--	--	--	--	--	--	--	--
As, tot.	mg/L	0.0006	0.0006	0.0006	0.0006	0.0006	0.0011	0.0011	--	0.00109
As, diss.	mg/L	--	--	--	0.0006	--	--	--	--	--
Ba, tot.	mg/L	0.058	0.056	0.055	0.053	0.060	0.054	0.0596	--	0.0639
Be, tot.	mg/L	--	--	--	--	--	--	<0.00004	--	<0.00004
Be, diss.	mg/L	<0.001	<0.001	<0.001	<0.001	--	--	--	--	--
Cd, tot.	mg/L	0.002	<0.001	<0.001	<0.001	<0.0002	<0.001	<0.00002	--	<0.00002
Cr, tot.	mg/L	0.003	<0.001	<0.001	<0.001	0.008	<0.001	0.00033	0.0003	0.00013
Co, tot.	mg/L	0.001	0.0005	<0.001	<0.001	<0.001	--	0.00008	--	0.00009
Cu, tot.	mg/L	0.002	<0.001	<0.001	<0.001	0.0008	<0.001	0.000445	--	0.0003
Fe, tot.	mg/L	0.033	0.028	0.019	0.025	0.023	0.043	0.013	0.032	0.013
Fe, ext.	mg/L	0.005	--	--	--	--	--	--	0.011	--
Pb, tot.	mg/L	--	--	--	--	0.0008	<0.005	0.000191	--	0.000094
Pb, ext.	mg/L	<0.002	<0.002	<0.002	<0.002	--	--	--	--	--
Mn, tot.	mg/L	0.008	0.014	0.015	0.011	0.013	0.006	0.0161	0.0133	0.00925
Hg, tot.	ug/L	<0.1	<0.1	<0.1	<0.04	<0.05	<0.04	<0.04	--	<0.005
Mo, tot.	mg/L	0.002	<0.001	<0.001	<0.001	--	--	0.00055	--	0.00062
Ni, tot.	mg/L	0.004	<0.001	<0.001	0.001	0.0034	0.001	0.0002	0.00029	0.00087
Se, tot.	mg/L	<0.0001	0.0001	<0.0001	--	--	--	0.0003	--	0.0003
Va, tot.	mg/L	0.003	<0.002	<0.002	<0.002	--	--	0.00038	--	0.00043
Zn, tot.	mg/L	0.002	0.002	<0.001	<0.001	0.01	<0.001	0.00118	--	0.00116

-- = not analyzed

VARIABLE	UNITS	MIDDLE BASIN								
		92	93	94	95	96	97	98	99	2000
	No. Samples:	18	9	8	7	7	6	6	11	12
TP-Maxxam/ARCV	mg/L	0.083	0.088	0.081	0.060	0.104	0.084	0.090	0.059	0.060
TP-McIntyre	mg/L	0.0861	0.0986	0.1027	0.0690	0.1085	0.0812	0.0817	0.0688	0.0584
TDP-Maxxam/ARCV	mg/L	0.030	0.057	0.043	0.034	0.055	0.048	0.059	0.037	0.034
TDP-McIntyre	mg/L	0.0329	0.0381	0.0407	0.0375	0.0554	0.0489	0.0587	0.0376	0.0347
PO_4, diss. Ortho	mg/L	0.002	0.020	0.008	0.008	–	0.026	0.017	0.011	0.007
P, part.	mg/L	–	–	–	–	–	0.038	0.025	0.031	0.024
TKN	mg/L	2.22	1.74	1.91	1.60	1.36	1.67	1.81	1.57	1.55
NH_3, tot.	mg/L	–	–	–	–	0.120	–	–	–	–
NH_3, diss.	mg/L	0.098	0.122	0.189	0.094	–	0.156	0.151	0.167	0.063
NO_2+NO_3-N, diss.	mg/L	0.025	0.005	0.007	0.004	0.011	0.019	0.015	0.014	0.020
Nitrite, diss.	mg/L	0.007	0.002	0.002	0.002	–	0.004	0.004	0.003	0.001
TN	mg/L	2.262	1.745	1.974	1.632	1.385	1.678	1.824	1.641	1.588
N, part.	mg/L	–	0.45	0.38	0.20	–	0.16	–	–	–
Silica	mg/L	2.9	2.5	1.7	2.8	6.6	2.9	2.6	5.0	4.7
TOC	mg/L	–	–	–	–	18.4	–	–	–	–
TIC	mg/L	–	–	–	–	75.3	–	–	–	–
DOC	mg/L	18.3	18.8	18.1	18.0	18.4	17.2	18.7	16.7	16.1
DIC	mg/L	71.0	69.0	70.3	73.8	74.5	67.3	73.8	–	–
C, part.	mg/L	3.54	2.87	2.15	1.22	0.20	1.13	0.94	–	–
COD	mg/L	53	54	55	50	47	56	53	–	–
CHL *a*	mg/m3	48.2	28.9	26.6	13.6	22.1	16.5	11.8	11.3	9.4
Phenols	mg/L	0.013	0.010	0.008	0.009	0.001	0.010	0.010	–	–
Conductance	uSie/cm	703	693	690	696	708	676	720	711	–
TDS, calc.	mg/L	418	410	414	422	433	403	432	426	433
TDS	mg/L	476	479	481	478	–	465	489	484	491
NFR	mg/L	7	6	4	2	2	3	2	2	2
FR	mg/L	–	–	–	–	432	–	–	–	–
TR	mg/L	480	484	481	480	–	466	491	488	492
Turbidity	NTU	4.30	6.50	5.30	1.60	2.00	1.88	1.57	1.03	1.36
Total Alkalinity	mg/L	306	306	308	313	313	307	322	313	318
PP Alkalinity	mg/L	–	–	–	–	7.5	12.5	10.5	9.0	11.0
pH	units	8.53	8.68	8.52	8.62	8.44	8.65	8.59	8.52	8.61
Hardness	mg/L	163	166	166	166	173	154	159	165	167

VARIABLE	UNITS	MIDDLE BASIN								
		92	93	94	95	96	97	98	99	2000
Sodium, diss.	mg/L	99	95	98	99	103	97	110	102	105
Calcium, diss.	mg/L	24.0	27.0	25.3	26.0	28.5	23.8	24.9	26.7	28.5
Magnesium, diss.	mg/L	25.0	24.0	25.0	25.0	24.2	23.0	23.7	23.5	22.9
Potassium, diss.	mg/L	9.5	9.4	10.1	9.8	10.2	10.2	10.3	9.9	9.5
Chloride, diss.	mg/L	7.1	7.2	7.8	8.0	8.3	8.2	8.8	8.9	8.6
Sulphate, diss.	mg/L	69	62	64	66	63	60	64	65	69
Fluoride, diss.	mg/L	0.23	0.23	0.25	0.25	0.27	0.24	0.25	0.25	–
Bicarbonate	mg/L	362	357	363	353	359	344	365	358	361
Carbonate, diss.	mg/L	11	13	11	14	9	15	13	11	14
Secchi Depth	m	1.3	1.8	2.0	2.9	2.1	2.1	2.8	2.5	2.7
Al, tot.	mg/L	–	0.006	0.003	0.003	0.020	0.055	0.014	0.017	0.012
Al, ext.	mg/L	0.005	–	–	–	–	–	–	–	–
As, tot.	mg/L	0.0006	0.0005	0.0006	0.0006	0.0004	0.00105	0.0011	–	0.00124
As, diss.	mg/L	–	–	–	0.0006	–	–	–	–	–
Ba, tot.	mg/L	0.059	0.057	0.056	0.053	0.060	0.050	0.0592	–	0.0643
Be, tot.	mg/L	–	–	–	–	–	–	<0.00004	–	<0.00004
Be, diss.	mg/L	<0.001	<0.001	<0.001	<0.001	–	–	–	–	–
Cd, tot.	mg/L	0.002	<0.001	<0.001	<0.001	<0.0002	<0.001	<0.00002	–	<0.00002
Cr, tot.	mg/L	0.004	0.001	<0.001	<0.001	0.005	0.0005	0.00026	0.00028	0.00016
Co, tot.	mg/L	0.001	<0.001	<0.001	<0.001	–	–	0.00007	–	0.0001
Cu, tot.	mg/L	0.001	<0.001	<0.001	<0.001	0.0009	<0.001	<0.001	–	0.00039
Fe, tot.	mg/L	0.033	0.026	0.018	0.017	0.035	0.022	0.008	0.024	0.0155
Fe, ext.	mg/L	0.005	–	–	–	–	–	–	0.009	–
Pb, tot.	mg/L	–	–	–	–	0.0006	<0.005	0.00021	–	0.000089
Pb, ext.	mg/L	<0.002	<0.002	<0.002	<0.002	–	–	–	–	–
Mn, tot.	mg/L	0.009	0.015	0.013	0.011	0.013	0.008	0.0150	0.0148	0.01080
Hg, tot.	ug/L	<0.1	<0.1	<0.1	<0.04	<0.05	<0.04	<0.04	–	<0.005
Mo, tot.	mg/L	0.002	<0.001	<0.001	<0.001	–	–	0.00052	–	0.00061
Ni, tot.	mg/L	0.004	<0.001	<0.001	<0.001	0.0039	0.001	0.00019	0.00024	0.00021
Se, tot.	mg/L	<0.0001	<0.0001	<0.0001	–	–	–	0.0003	–	0.0003
Va, tot.	mg/L	0.004	<0.002	<0.002	<0.002	–	–	0.00037	–	0.00039
Zn, tot.	mg/L	0.002	0.002	<0.001	<0.001	0.008	<0.001	0.00128	–	0.00235

– = not analyzed

VARIABLE	UNITS	MIDDLE BASIN								
		92	93	94	95	96	97	98	99	2000
	No. Samples:	18	9	8	7	7	6	6	11	12
TP-Maxxam/ARCV	**mg/L**	**0.083**	**0.088**	**0.081**	**0.060**	**0.104**	**0.084**	**0.090**	**0.059**	**0.060**
TP-McIntyre	mg/L	0.0861	0.0986	0.1027	0.0690	0.1085	0.0812	0.0817	0.0688	0.0584
TDP-Maxxam/ARCV	**mg/L**	**0.030**	**0.057**	**0.043**	**0.034**	**0.055**	**0.048**	**0.059**	**0.037**	**0.034**
TDP-McIntyre	mg/L	0.0329	0.0381	0.0407	0.0375	0.0554	0.0489	0.0587	0.0376	0.0347
PO_4, diss. Ortho	**mg/L**	**0.002**	**0.020**	**0.008**	**0.008**	**–**	**0.026**	**0.017**	**0.011**	**0.007**
P, part.	mg/L	–	–	–	–	–	0.038	0.025	0.031	0.024
TKN	**mg/L**	**2.22**	**1.74**	**1.91**	**1.60**	**1.36**	**1.67**	**1.81**	**1.57**	**1.55**
NH_3, tot.	mg/L	–	–	–	–	0.120	–	–	–	–
NH_3, diss.	**mg/L**	**0.098**	**0.122**	**0.189**	**0.094**	**–**	**0.156**	**0.151**	**0.167**	**0.063**
NO_2+NO_3-N, diss.	mg/L	0.025	0.005	0.007	0.004	0.011	0.019	0.015	0.014	0.020
Nitrite, diss.	**mg/L**	**0.007**	**0.002**	**0.002**	**0.002**	**–**	**0.004**	**0.004**	**0.003**	**0.001**
TN	mg/L	2.262	1.745	1.974	1.632	1.385	1.678	1.824	1.641	1.588
N, part.	**mg/L**	**–**	**0.45**	**0.38**	**0.20**	**–**	**0.16**	**–**	**–**	**–**
Silica	mg/L	2.9	2.5	1.7	2.8	6.6	2.9	2.6	5.0	4.7
TOC	**mg/L**	**–**	**–**	**–**	**–**	**18.4**	**–**	**–**	**–**	**–**
TIC	mg/L	–	–	–	–	75.3	–	–	–	–
DOC	**mg/L**	**18.3**	**18.8**	**18.1**	**18.0**	**18.4**	**17.2**	**18.7**	**16.7**	**16.1**
DIC	mg/L	71.0	69.0	70.3	73.8	74.5	67.3	73.8	–	–
C, part.	**mg/L**	**3.54**	**2.87**	**2.15**	**1.22**	**0.20**	**1.13**	**0.94**	**–**	**–**
COD	mg/L	53	54	55	50	47	56	53	–	–
CHL *a*	**mg/m3**	**48.2**	**28.9**	**26.6**	**13.6**	**22.1**	**16.5**	**11.8**	**11.3**	**9.4**
Phenols	mg/L	0.013	0.010	0.008	0.009	0.001	0.010	0.010	–	–
Conductance	**uSie/cm**	**703**	**693**	**690**	**696**	**708**	**676**	**720**	**711**	**–**
TDS, calc.	mg/L	418	410	414	422	433	403	432	426	433
TDS	**mg/L**	**476**	**479**	**481**	**478**	**–**	**465**	**489**	**484**	**491**
NFR	mg/L	7	6	4	2	2	3	2	2	2
FR	**mg/L**	**–**	**–**	**–**	**–**	**432**	**–**	**–**	**–**	**–**
TR	mg/L	480	484	481	480	–	466	491	488	492
Turbidity	**NTU**	**4.30**	**6.50**	**5.30**	**1.60**	**2.00**	**1.88**	**1.57**	**1.03**	**1.36**
Total Alkalinity	mg/L	306	306	308	313	313	307	322	313	318
PP Alkalinity	**mg/L**	**–**	**–**	**–**	**–**	**7.5**	**12.5**	**10.5**	**9.0**	**11.0**
pH	units	8.53	8.68	8.52	8.62	8.44	8.65	8.59	8.52	8.61
Hardness	**mg/L**	**163**	**166**	**166**	**166**	**173**	**154**	**159**	**165**	**167**

VARIABLE	UNITS	MIDDLE BASIN								
		92	93	94	95	96	97	98	99	2000
Sodium, diss.	mg/L	99	95	98	99	103	97	110	102	105
Calcium, diss.	mg/L	24.0	27.0	25.3	26.0	28.5	23.8	24.9	26.7	28.5
Magnesium, diss.	mg/L	25.0	24.0	25.0	25.0	24.2	23.0	23.7	23.5	22.9
Potassium, diss.	mg/L	9.5	9.4	10.1	9.8	10.2	10.2	10.3	9.9	9.5
Chloride, diss.	mg/L	7.1	7.2	7.8	8.0	8.3	8.2	8.8	8.9	8.6
Sulphate, diss.	mg/L	69	62	64	66	63	60	64	65	69
Fluoride, diss.	mg/L	0.23	0.23	0.25	0.25	0.27	0.24	0.25	0.25	--
Bicarbonate	mg/L	362	357	363	353	359	344	365	358	361
Carbonate, diss.	mg/L	11	13	11	14	9	15	13	11	14
Secchi Depth	m	1.3	1.8	2.0	2.9	2.1	2.1	2.8	2.5	2.7
Al, tot.	mg/L	--	0.006	0.003	0.003	0.020	0.055	0.014	0.017	0.012
Al, ext.	mg/L	0.005	--	--	--	--	--	--	--	--
As, tot.	mg/L	0.0006	0.0005	0.0006	0.0006	0.0004	0.00105	0.0011	--	0.00124
As, diss.	mg/L	--	--	--	0.0006	--	--	--	--	--
Ba, tot.	mg/L	0.059	0.057	0.056	0.053	0.060	0.050	0.0592	--	0.0643
Be, tot.	mg/L	--	--	--	--	--	--	<0.00004	--	<0.00004
Be, diss.	mg/L	<0.001	<0.001	<0.001	<0.001	--	--	--	--	--
Cd, tot.	mg/L	0.002	<0.001	<0.001	<0.001	<0.0002	<0.001	<0.00002	--	<0.00002
Cr, tot.	mg/L	0.004	0.001	<0.001	<0.001	0.005	0.0005	0.00026	0.00028	0.00016
Co, tot.	mg/L	0.001	<0.001	<0.001	<0.001	--	--	0.00007	--	0.0001
Cu, tot.	mg/L	0.001	<0.001	<0.001	<0.001	0.0009	<0.001	<0.001	--	0.00039
Fe, tot.	mg/L	0.033	0.026	0.018	0.017	0.035	0.022	0.008	0.024	0.0155
Fe, ext.	mg/L	0.005	--	--	--	--	--	--	0.009	--
Pb, tot.	mg/L	--	--	--	--	0.0006	<0.005	0.00021	--	0.000089
Pb, ext.	mg/L	<0.002	<0.002	<0.002	<0.002	--	--	--	--	--
Mn, tot.	mg/L	0.009	0.015	0.013	0.011	0.013	0.008	0.0150	0.0148	0.01080
Hg, tot.	ug/L	<0.1	<0.1	<0.1	<0.04	<0.05	<0.04	<0.04	--	<0.005
Mo, tot.	mg/L	0.002	<0.001	<0.001	<0.001	--	--	0.00052	--	0.00061
Ni, tot.	mg/L	0.004	<0.001	<0.001	<0.001	0.0039	0.001	0.00019	0.00024	0.00021
Se, tot.	mg/L	<0.0001	<0.0001	<0.0001	--	--	--	0.0003	--	0.0003
Va, tot.	mg/L	0.004	<0.002	<0.002	<0.002	--	--	0.00037	--	0.00039
Zn, tot.	mg/L	0.002	0.002	<0.001	<0.001	0.008	<0.001	0.00128	--	0.00235

-- = not analyzed

VARIABLE	UNITS	NORTH BASIN								
		92	93	94	95	96	97	98	99	2000
No. Samples:		18	9	8	7	7	6	6	11	12
TP-Maxxam/ARCV	mg/L	0.070	0.093	0.078	0.066	0.093	0.095	0.087	0.062	0.062
TP-McIntyre	mg/L	0.0895	0.0974	0.0880	0.0765	0.1151	0.0922	0.0874	0.0715	0.0612
TDP-Maxxam/ARCV	mg/L	0.032	0.038	0.034	0.043	0.043	0.035	0.062	0.030	0.039
TDP-McIntyre	mg/L	0.0337	0.0354	0.0356	0.0455	0.0509	0.0394	0.0623	0.0325	0.0412
PO_4, diss. Ortho	mg/L	0.002	0.007	0.001	0.011	–	0.004	0.016	0.005	0.013
P, part.	mg/L	–	–	–	–	0.056	0.062	0.030	0.032	0.020
TKN	mg/L	1.94	1.68	1.85	1.60	1.65	1.88	1.82	1.51	1.43
NH_3, tot.	mg/L	–	–	–	–	0.110	–	–	–	–
NH_3, diss.	mg/L	0.090	0.044	0.174	0.100	0.318	0.079	0.187	0.112	0.074
NO_2+NO_3-N, diss.	mg/L	0.014	0.009	0.008	0.011	0.022	0.017	0.013	0.007	0.027
Nitrite, diss.	mg/L	0.007	0.003	0.002	0.003	0.020	0.007	0.006	0.004	0.001
TN	mg/L	1.943	1.696	1.853	1.613	1.669	1.919	1.859	1.569	1.532
N, part.	mg/L	–	0.39	0.36	0.22	0.34	0.25	–	–	–
Silica	mg/L	3.1	2.7	2.6	3.0	7.2	2.4	3.4	5.0	4.5
TOC	mg/L	–	–	–	–	18.5	–	–	–	–
TIC	mg/L	–	–	–	–	75.0	–	–	–	–
DOC	mg/L	18.3	18.3	17.7	18.3	17.4	16.5	18.8	16.6	16.1
DIC	mg/L	70.3	69.0	69.2	72.6	72.7	68.0	74.0	–	–
C, part.	mg/L	4.24	2.23	2.05	1.18	0.20	1.76	1.07	–	–
COD	mg/L	54	53	53	44	45	55	54	–	–
CHL a	mg/m3	39.4	32.2	26.1	11.0	23.7	26.9	12.1	9.5	7.6
Phenols	mg/L	0.013	0.010	0.008	0.010	0.001	0.010	0.009	–	–
Conductance	uSie/cm	705	693	687	697	711	680	720	705	–
TDS, calc.	mg/L	420	409	410	423	431	402	439	421	435
TDS	mg/L	475	473	475	479	485	466	489	473	491
NFR	mg/L	6	4	3	2	1	4	2	3	2
FR	mg/L	–	–	–	–	420	–	–	–	–
TR	mg/L	478	475	476	484	490	469	490	476	492
Turbidity	NTU	2.60	4.50	5.20	1.30	3.00	3.50	1.59	1.38	1.27
Total Alkalinity	mg/L	307	305	307	313	311	306	322	310	318
PP Alkalinity	mg/L	–	–	–	–	10.5	13.5	10.5	7.0	11.0
pH	units	8.62	8.64	8.54	8.61	8.54	8.67	8.58	8.46	8.59
Hardness	mg/L	160	168	165	168	168	153	159	163	167

VARIABLE	UNITS	NORTH BASIN								
		92	93	94	95	96	97	98	99	2000
Sodium, diss.	mg/L	99	96	97	100	105	99	111	101	105
Calcium, diss.	mg/L	24.0	27.0	26.0	26.0	28.4	23.5	24.8	27.8	28.6
Magnesium, diss.	mg/L	24.0	24.0	25.0	25.0	24.4	22.7	23.9	22.7	23.0
Potassium, diss.	mg/L	9.4	9.4	10.0	9.9	10.4	10.2	10.5	9.8	9.6
Chloride, diss.	mg/L	7.1	7.3	7.8	8.1	8.6	8.3	8.7	8.8	8.7
Sulphate, diss.	mg/L	69	62	63	66	63	60	65	65	70
Fluoride, diss.	mg/L	0.23	0.23	0.24	0.25	0.27	0.24	0.26	0.25	–
Bicarbonate	mg/L	362	360	360	358	356	341	370	364	362
Carbonate, diss.	mg/L	13	13	10	13	13	17	13	8	13
Secchi Depth	m	1.6	1.7	2.1	3.7	2.0	1.4	2.9	2.8	2.8
Al, tot.	mg/L	–	0.004	0.003	0.003	0.020	0.085	0.013	0.014	0.011
Al, ext.	mg/L	0.005	–	–	–	–	–	–	–	–
As, tot.	mg/L	0.0006	0.00058	0.0006	0.0006	0.0005	0.0011	0.0011	–	0.00115
As, diss.	mg/L	–	–	–	0.0006	–	–	–	–	–
Ba, tot.	mg/L	0.060	0.056	0.055	0.054	0.060	0.051	0.0579	–	0.0653
Be, tot.	mg/L	–	–	–	–	–	–	<0.00004	–	0.000064
Be, diss.	mg/L	<0.001	<0.001	<0.001	<0.001	–	–	–	–	–
Cd, tot.	mg/L	0.002	<0.001	<0.001	<0.001	<0.0002	<0.001	<0.00002	–	<0.00002
Cr, tot.	mg/L	0.003	<0.001	<0.001	<0.001	0.003	<0.001	0.00036	0.0003	0.00009
Co, tot.	mg/L	0.001	<0.001	<0.001	<0.001	–	–	0.00007	–	0.00013
Cu, tot.	mg/L	0.001	<0.001	<0.001	<0.001	0.0011	<0.001	0.00055	–	0.00038
Fe, tot.	mg/L	0.032	0.026	0.02	0.028	0.045	0.042	0.011	0.027	0.0125
Fe, ext.	mg/L	0.005	–	–	–	–	–	–	0.019	–
Pb, tot.	mg/L	–	–	–	–	0.0007	<0.005	0.00019	–	0.000105
Pb, ext.	mg/L	<0.002	<0.002	<0.002	<0.002	–	–	–	–	–
Mn, tot.	mg/L	0.009	0.019	0.017	0.012	0.017	0.007	0.0140	0.0177	0.0150
Hg, tot.	ug/L	<0.1	<0.1	<0.1	<0.04	<0.05	<0.04	<0.04	–	<0.005
Mo, tot.	mg/L	0.001	<0.001	<0.001	<0.001	–	–	0.00053	–	0.00061
Ni, tot.	mg/L	0.003	<0.001	<0.001	<0.001	0.0035	0.001	0.00021	0.0004	0.0002
Se, tot.	mg/L	<0.0001	0.0001	<0.0001	–	–	–	0.0003	–	0.0003
Va, tot.	mg/L	0.004	<0.002	<0.002	<0.002	–	–	0.00037	–	0.00037
Zn, tot.	mg/L	0.002	0.001	<0.001	<0.001	0.01888	0.001	0.0044	–	0.00178

-- = not analyzed

VARIABLE	UNITS	NORTH BASIN								
		92	93	94	95	96	97	98	99	2000
No. Samples:		18	9	8	7	7	6	6	11	12
TP-Maxxam/ARCV	mg/L	0.070	0.093	0.078	0.066	0.093	0.095	0.087	0.062	0.062
TP-McIntyre	mg/L	0.0895	0.0974	0.0880	0.0765	0.1151	0.0922	0.0874	0.0715	0.0612
TDP-Maxxam/ARCV	mg/L	0.032	0.038	0.034	0.043	0.043	0.035	0.062	0.030	0.039
TDP-McIntyre	mg/L	0.0337	0.0354	0.0356	0.0455	0.0509	0.0394	0.0623	0.0325	0.0412
PO_4, diss. Ortho	mg/L	0.002	0.007	0.001	0.011	—	0.004	0.016	0.005	0.013
P, part.	mg/L	--	--	--	--	0.056	0.062	0.030	0.032	0.020
TKN	mg/L	1.94	1.68	1.85	1.60	1.65	1.88	1.82	1.51	1.43
NH_3, tot.	mg/L	--	--	--	--	0.110	--	--	--	--
NH_3, diss.	mg/L	0.090	0.044	0.174	0.100	0.318	0.079	0.187	0.112	0.074
NO_2+NO_3-N, diss.	mg/L	0.014	0.009	0.008	0.011	0.022	0.017	0.013	0.007	0.027
Nitrite, diss.	mg/L	0.007	0.003	0.002	0.003	0.020	0.007	0.006	0.004	0.001
TN	mg/L	1.943	1.696	1.853	1.613	1.669	1.919	1.859	1.569	1.532
N, part.	mg/L	—	0.39	0.36	0.22	0.34	0.25	—	—	—
Silica	mg/L	3.1	2.7	2.6	3.0	7.2	2.4	3.4	5.0	4.5
TOC	mg/L	—	—	—	—	18.5	—	—	—	—
TIC	mg/L	--	--	--	--	75.0	--	--	--	--
DOC	mg/L	18.3	18.3	17.7	18.3	17.4	16.5	18.8	16.6	16.1
DIC	mg/L	70.3	69.0	69.2	72.6	72.7	68.0	74.0	--	--
C, part.	mg/L	4.24	2.23	2.05	1.18	0.20	1.76	1.07	—	—
COD	mg/L	54	53	53	44	45	55	54	--	--
CHL a	mg/m3	39.4	32.2	26.1	11.0	23.7	26.9	12.1	9.5	7.6
Phenols	mg/L	0.013	0.010	0.008	0.010	0.001	0.010	0.009	--	--
Conductance	uSie/cm	705	693	687	697	711	680	720	705	—
TDS, calc.	mg/L	420	409	410	423	431	402	439	421	435
TDS	mg/L	475	473	475	479	485	466	489	473	491
NFR	mg/L	6	4	3	2	1	4	2	3	2
FR	mg/L	—	—	—	—	420	—	—	—	—
TR	mg/L	478	475	476	484	490	469	490	476	492
Turbidity	NTU	2.60	4.50	5.20	1.30	3.00	3.50	1.59	1.38	1.27
Total Alkalinity	mg/L	307	305	307	313	311	306	322	310	318
PP Alkalinity	mg/L	—	—	—	—	10.5	13.5	10.5	7.0	11.0
pH	units	8.62	8.64	8.54	8.61	8.54	8.67	8.58	8.46	8.59
Hardness	mg/L	160	168	165	168	168	153	159	163	167

VARIABLE	**UNITS**	**NORTH BASIN**								
		92	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**2000**
Sodium, diss.	mg/L	99	96	97	100	105	99	111	101	105
Calcium, diss.	**mg/L**	24.0	27.0	26.0	26.0	28.4	23.5	24.8	27.8	28.6
Magnesium, diss.	mg/L	24.0	24.0	25.0	25.0	24.4	22.7	23.9	22.7	23.0
Potassium, diss.	**mg/L**	9.4	9.4	10.0	9.9	10.4	10.2	10.5	9.8	9.6
Chloride, diss.	mg/L	7.1	7.3	7.8	8.1	8.6	8.3	8.7	8.8	8.7
Sulphate, diss.	**mg/L**	69	62	63	66	63	60	65	65	70
Fluoride, diss.	mg/L	0.23	0.23	0.24	0.25	0.27	0.24	0.26	0.25	--
Bicarbonate	**mg/L**	362	360	360	358	356	341	370	364	362
Carbonate, diss.	mg/L	13	13	10	13	13	17	13	8	13
Secchi Depth	**m**	1.6	1.7	2.1	3.7	2.0	1.4	2.9	2.8	2.8
Al, tot.	mg/L	--	0.004	0.003	0.003	0.020	0.085	0.013	0.014	0.011
Al, ext.	**mg/L**	0.005	--	--	--	--	--	--	--	--
As, tot.	mg/L	0.0006	0.00058	0.0006	0.0006	0.0005	0.0011	0.0011	--	0.00115
As, diss.	**mg/L**	--	--	--	0.0006	--	--	--	--	--
Ba, tot.	mg/L	0.060	0.056	0.055	0.054	0.060	0.051	0.0579	--	0.0653
Be, tot.	**mg/L**	--	--	--	--	--	--	<0.00004	--	0.000064
Be, diss.	mg/L	<0.001	<0.001	<0.001	<0.001	--	--	--	--	--
Cd, tot.	**mg/L**	0.002	<0.001	<0.001	<0.001	<0.0002	<0.001	<0.00002	--	<0.00002
Cr, tot.	mg/L	0.003	<0.001	<0.001	<0.001	0.003	<0.001	0.00036	0.0003	0.00009
Co, tot.	**mg/L**	0.001	<0.001	<0.001	<0.001	--	--	0.00007	--	0.00013
Cu, tot.	mg/L	0.001	<0.001	<0.001	<0.001	0.0011	<0.001	0.00055	--	0.00038
Fe, tot.	**mg/L**	0.032	0.026	0.02	0.028	0.045	0.042	0.011	0.027	0.0125
Fe, ext.	mg/L	0.005	--	--	--	--	--	--	0.019	--
Pb, tot.	**mg/L**	--	--	--	--	0.0007	<0.005	0.00019	--	0.000105
Pb, ext.	mg/L	<0.002	<0.002	<0.002	<0.002	--	--	--	--	--
Mn, tot.	**mg/L**	0.009	0.019	0.017	0.012	0.017	0.007	0.0140	0.0177	0.0150
Hg, tot.	ug/L	<0.1	<0.1	<0.1	<0.04	<0.05	<0.04	<0.04	--	<0.005
Mo, tot.	**mg/L**	0.001	<0.001	<0.001	<0.001	--	--	0.00053	--	0.00061
Ni, tot.	mg/L	0.003	<0.001	<0.001	<0.001	0.0035	0.001	0.00021	0.0004	0.0002
Se, tot.	**mg/L**	<0.0001	0.0001	<0.0001	--	--	--	0.0003	--	0.0003
Va, tot.	mg/L	0.004	<0.002	<0.002	<0.002	--	--	0.00037	--	0.00037
Zn, tot.	**mg/L**	0.002	0.001	<0.001	<0.001	0.01888	0.001	0.0044	--	0.00178

-- = not analyzed

Appendix 1b Median values for samples collected during the open-water season from Ghostpine Creek sites, 1986-2000

VARIABLE	UNITS	GHOSTPINE CREEK AT R.R. 245					
		89	92	93	98	99	00
No. Samples:		6	42	16	2	14	6
TP-ARCV	mg/L	0.065	0.097	0.150	0.146	0.103	0.113
TP-Maxxam	mg/L	–[a]	–	–		–	–
TDP-ARCV	mg/L	0.040	0.038	–	0.085	0.070	0.082
TDP-Maxxam	mg/L	–	–	–		–	–
PO_4, diss. Ortho	mg/L	–	0.003	–		–	–
P, part.	mg/L	–	–	–	0.061	0.018	0.018
TKN	mg/L	1.42	1.80	1.85	1.71	1.57	1.43
NH_3, tot.	mg/L	–	–	–	–	–	–
NH_3, diss.	mg/L	0.033	0.040	–	0.132	0.082	0.071
NO_2+NO_3-N, diss.	mg/L	0.005	0.004	–	0.040	0.014	0.029
Nitrite, diss.	mg/L	–	0.002	–	–	–	0.002
TN	mg/L	–	–	–	–	–	–
N, part.	mg/L	–	–	–	–	–	–
Silica	mg/L	–	2.4	–	–	–	–
TOC	mg/L	–	–	–	–	–	–
TIC	mg/L	–	–	–	–	–	–
DOC	mg/L	–	–	–	–	–	–
DIC	mg/L	–	–	–	–	–	–
C, part.	mg/L	–	–	–	–	–	–
COD	mg/L	–	–	–	–	–	–
CHL *a*	mg/m3	–	–	–	–	2.6	3.8
Phenols	mg/L	–	–	–	–	–	–
Dissolved Oxygen	mg/L	8.5	8.7	–	6.2	7.0	8.8
Water Temp	deg C	10.65	11.60	–	14.17	15.73	18.45
Air Temp	deg C	17.5	16.0	–	15.0	–	21.0
Colour, True	TCU	–	59	–	–	–	44
Conductance	uS/cm	633	703	–	862	722	735
TDS, calc.	mg/L	–	426	–	–	–	–
TDS	mg/L	–	482	–	–	–	513
NFR	mg/L	–	6	–	–	4	1
FR	mg/L	–	–	–	–	–	–
Total Residue	mg/L	–	491	–	–	–	514
Turbidity	NTU	–	4.05	–	–	1.52	1.67

VARIABLE	**UNITS**	**GHOSTPINE CREEK AT R.R. 245**					
		89	**92**	**93**	**98**	**99**	**00**
No. Samples:		6	42	16	2	14	6
Total Alkalinity	mg/L	--	314	--	--	--	--
PP Alkalinity	**mg/L**	--	--	--	--	--	--
pH	units	8.20	8.20	--	7.74	8.30	8.19
Hardness	**mg/L**	--	177	--	--	--	--
Sodium, diss.	mg/L	--	99	--	--	--	--
Calcium, diss.	**mg/L**	--	29.0	--	--	--	34.0
Magnesium, diss.	mg/L	--	25.0	--	--	--	--
Potassium, diss.	**mg/L**	--	9.6	--	--	--	--
Chloride, diss.	mg/L	--	7.0	--	--	--	--
Chlorine, ext.	**mg/L**						11.6
Sulphate, diss.	mg/L	--	68	--	--	--	--
Sulphide, diss.	**mg/L**	--	--	--	0.007	0.002	0.003
Fluoride, diss.	mg/L	--	0.23	--	--	--	--
Bicarbonate	**mg/L**	--	367	--	--	--	--
Carbonate, diss.	mg/L	--	13	--	--	--	--
Odour	**TON**	--	--	--	--	0.5	1.0
Secchi Depth	m	--	--	--	--	--	--
Total Coliforms	**no./dL**	--	58	--	--	--	--
Fecal Coliforms	no./dL	--	22	--	--	--	43
Escherichia Coli	**no./dL**	--	--	--	--	--	35
Ag, ext.	mg/L	--	--	--	--	--	***<0.000005***
Al, tot.	**mg/L**	--	--	--	--	--	--
Al, ext.	mg/L	--	--	--	--	--	0.025
As, tot.	**mg/L**	--	--	--	--	--	--
As, diss.	mg/L	--	--	--	--	--	--
As, ext.	**mg/L**	--	--	--	--	--	***0.00135***
B, ext.	mg/L	--	--	--	--	--	***0.0777***
Ba, tot.	**mg/L**	--	--	--	--	--	--
Ba, ext.	mg/L	--	--	--	--	--	***0.0693***
Be, tot.	**mg/L**	--	--	--	--	--	--
Be, diss.	mg/L	--	--	--	--	--	--
Be, ext.	**mg/L**	--	--	--	--	--	***0.0002***
Bi, ext.	mg/L	--	--	--	--	--	***<0.000005***
Cd, tot.	**mg/L**	--	--	--	--	--	--

Appendix 1b Median values for samples collected during the open-water season from Ghostpine Creek sites, 1986-2000

VARIABLE	UNITS	GHOSTPINE CREEK AT R.R. 245					
		89	92	93	98	99	00
	No. Samples:	6	42	16	2	14	6
TP-ARCV	**mg/L**	0.065	0.097	0.150	0.146	0.103	0.113
TP-Maxxam	mg/L	--[a]	--	--		--	--
TDP-ARCV	**mg/L**	0.040	0.038	--	0.085	0.070	0.082
TDP-Maxxam	mg/L	--	--	--		--	--
PO_4, diss. Ortho	**mg/L**	--	0.003	--		--	--
P, part.	mg/L	--	--	--	0.061	0.018	0.018
TKN	**mg/L**	1.42	1.80	1.85	1.71	1.57	1.43
NH_3, tot.	mg/L	--	--	--	--	--	--
NH_3, diss.	**mg/L**	0.033	0.040	--	0.132	0.082	0.071
NO_2+NO_3-N, diss.	mg/L	0.005	0.004	--	0.040	0.014	0.029
Nitrite, diss.	**mg/L**	--	0.002	--	--	--	0.002
TN	mg/L	--	--	--	--	--	--
N, part.	**mg/L**	--	--	--	--	--	--
Silica	mg/L	--	2.4	--	--	--	--
TOC	**mg/L**	--	--	--	--	--	--
TIC	mg/L	--	--	--	--	--	--
DOC	**mg/L**	--	--	--	--	--	--
DIC	mg/L	--	--	--	--	--	--
C, part.	**mg/L**	--	--	--	--	--	--
COD	mg/L	--	--	--	--	--	--
CHL *a*	**mg/m3**	--	--	--	--	2.6	3.8
Phenols	mg/L	--	--	--	--	--	--
Dissolved Oxygen	**mg/L**	8.5	8.7	--	6.2	7.0	8.8
Water Temp	deg C	10.65	11.60	--	14.17	15.73	18.45
Air Temp	**deg C**	17.5	16.0	--	15.0	--	21.0
Colour, True	TCU	--	59	--	--	--	44
Conductance	**uS/cm**	633	703	--	862	722	735
TDS, calc.	mg/L	--	426	--	--	--	--
TDS	**mg/L**	--	482	--	--	--	513
NFR	mg/L	--	6	--	--	4	1
FR	**mg/L**	--	--	--	--	--	--
Total Residue	mg/L	--	491	--	--	--	514
Turbidity	**NTU**	--	4.05	--	--	1.52	1.67

VARIABLE	**UNITS**	**GHOSTPINE CREEK AT R.R. 245**					
		89	**92**	**93**	**98**	**99**	**00**
No. Samples:		6	42	16	2	14	6
Total Alkalinity	mg/L	--	314	--	--	--	--
PP Alkalinity	**mg/L**	–	–	–	–	–	–
pH	units	8.20	8.20	--	7.74	8.30	8.19
Hardness	**mg/L**	–	177	–	–	–	–
Sodium, diss.	mg/L	--	99	--	--	--	--
Calcium, diss.	**mg/L**	–	29.0	–	–	–	34.0
Magnesium, diss.	mg/L	--	25.0	--	--	--	--
Potassium, diss.	**mg/L**	–	9.6	–	–	–	–
Chloride, diss.	mg/L	--	7.0	--	--	--	--
Chlorine, ext. -	**mg/L**						11.6
Sulphate, diss.	mg/L	--	68	--	--	--	--
Sulphide, diss.	**mg/L**	–	–	–	0.007	0.002	0.003
Fluoride, diss.	mg/L	--	0.23	--	--	--	--
Bicarbonate	**mg/L**	–	367	–	–	–	–
Carbonate, diss.	mg/L	--	13	--	--	--	--
Odour	**TON**	–	–	–	–	0.5	1.0
Secchi Depth	m	--	--	--	--	--	--
Total Coliforms	**no./dL**	–	58	–	–	–	–
Fecal Coliforms	no./dL	--	22	--	--	--	43
Escherichia Coli	**no./dL**	–	–	–	–	–	35
Ag, ext.	mg/L	--	--	--	--	--	***<0.000005***
Al, tot.	**mg/L**	–	–	–	–	–	–
Al, ext.	mg/L	--	--	--	--	--	0.025
As, tot.	**mg/L**	–	–	–	–	–	–
As, diss.	mg/L	--	--	--	--	--	--
As, ext.	**mg/L**	–	–	–	–	–	***0.00135***
B, ext.	mg/L	--	--	--	--	--	***0.0777***
Ba, tot.	**mg/L**	–	–	–	–	–	–
Ba, ext.	mg/L	--	--	--	--	--	***0.0693***
Be, tot.	**mg/L**	–	–	–	–	–	–
Be, diss.	mg/L	--	--	--	--	--	--
Be, ext.	**mg/L**	–	–	–	–	–	***0.0002***
Bi, ext.	mg/L	--	--	--	--	--	***<0.000005***
Cd, tot.	**mg/L**	–	–	–	–	–	–

VARIABLE	UNITS	GHOSTPINE CREEK AT R.R. 245 89	92	93	98	99	00
	No. Samples:	6	42	16	2	14	6
Cd, ext.	mg/L	--	--	--	--	--	***<0.00001***
Cr, tot.	mg/L	--	--	--	--	--	--
Cr, ext.	mg/L	--	--	--	--	--	***0.0002***
Co, tot.	mg/L	--	--	--	--	--	--
Co, ext.	mg/L	--	--	--	--	--	***0.00013***
Cu, tot.	mg/L	--	--	--	--	--	--
Cu, ext.	mg/L	--	--	--	--	--	***0.00035***
Fe, tot.	mg/L	--	--	--	--	--	--
Fe, ext.	mg/L	--	0.02	--	--	--	0.087
Li, ext.	mg/L	--	--	--	--	--	***0.031***
Pb, tot.	mg/L	--	--	--	--	--	--
Pb, ext.	mg/L	--	--	--	--	--	***0.00014***
Mn, tot.	mg/L	--	--	--	--	--	--
Mn, ext.	mg/L	--	--	--	--	--	0.043
Hg, tot.	ug/L	--	--	--	--	--	--
Mo, tot.	mg/L	--	--	--	--	--	--
Mo, ext.	mg/L	--	--	--	--	--	***0.00058***
Ni, tot.	mg/L	--	--	--	--	--	--
Ni, ext.	mg/L	--	--	--	--	--	***0.00032***
Sb, ext.	mg/L	--	--	--	--	--	***0.00011***
Se, tot.	mg/L	--	--	--	--	--	--
Se, ext.	mg/L	--	--	--	--	--	***<0.0005***
Sn, ext.	mg/L	--	--	--	--	--	***<0.0001***
Sr, ext.	mg/L	--	--	--	--	--	***0.3***
Th, ext.	mg/L	--	--	--	--	--	***0.000005***
Ti, ext.	mg/L	--	--	--	--	--	***0.001***
Tl, ext.	mg/L	--	--	--	--	--	***<0.000003***
U, ext.	mg/L	--	--	--	--	--	***0.00079***
Va, tot.	mg/L	--	--	--	--	--	--
Va, ext.	mg/L	--	--	--	--	--	***0.00049***
Zn, tot.	mg/L	--	--	--	--	--	--
Zn, ext.	mg/L	--	--	--	--	--	***0.00127***

Notes:

[a] hyphens indicate that a variable was not measured **bold/italics = one sample only**

VARIABLE	UNITS	GHOSTPINE CREEK AT HWY 585 NEAR TROCHU			GHOSTPINE CREEK AT HWY 27		
		86	99	00	86	99	00
	No. Samples:	4	6	5	4	11	6
TP-ARCV	mg/L	--	0.315	0.485	--	0.253	0.471
TP-Maxxam	mg/L	0.495	--	--	0.420	--	--
TDP-ARCV	mg/L	--	0.203	0.333	--	0.206	0.406
TDP-Maxxam	mg/L	--	--	--	--	--	--
PO_4, diss. Ortho	mg/L	0.385	--	--	0.293	--	--
P, part.	mg/L	--	0.048	0.057	--	0.042	0.065
TKN	mg/L	2.03	2.00	2.12	2.07	1.83	2.33
NH_3, tot.	mg/L	0.090	--	--	0.055	--	--
NH_3, diss.	mg/L	--	0.034	0.026	--	0.022	0.025
NO_2+NO_3-N, diss.	mg/L	0.015	0.006	0.006	0.026	0.003	0.008
Nitrite, diss.	mg/L	--	--	--	--	--	--
TN	mg/L	--	--	--	--	--	--
N, part.	mg/L	--	--	--	--	--	--
Silica	mg/L	10.3	--	--	4.3	--	--
TOC	mg/L	22.0	--	--	23.7	--	--
TIC	mg/L	94.0	--	--	82.3	--	--
DOC	mg/L	--	--	--	--	--	--
DIC	mg/L	--	--	--	--	--	--
C, part.	mg/L	--	--	--	--	--	--
COD	mg/L	70	--	--	73	--	--
CHL *a*	mg/m3	--	3.9	4.8	--	7.4	10.2
Phenols	mg/L	0.016	--	--	0.011	--	--
Dissolved Oxygen	mg/L	5.7	11.4	11.1	8.6	10.2	9.9
Water Temp	deg C	16.00	10.53	19.34	16.00	15.67	16.64
Air Temp	deg C	--	--	22.0	--	--	17.0
Colour, True	TCU	200	--	--	250	--	--
Conductance	uS/cm	1415	1139	1540	1305	1354	1645
TDS, calc.	mg/L	--	--	--	--	--	--
TDS	mg/L	--	--	--	--	--	--
NFR	mg/L	15	--	8	30	--	7
FR	mg/L	891	--	--	838	--	--
Total Residue	mg/L	--	--	--	--	--	--
Turbidity	NTU	19.00	--	8.30	40.00	--	9.10

VARIABLE	UNITS	GHOSTPINE CREEK AT R.R. 245					
		89	92	93	98	99	00
	No. Samples:	6	42	16	2	14	6
Cd, ext.	mg/L	--	--	--	--	--	***<0.00001***
Cr, tot.	mg/L	--	--	--	--	--	--
Cr, ext.	mg/L	--	--	--	--	--	***0.0002***
Co, tot.	mg/L	--	--	--	--	--	--
Co, ext.	mg/L	--	--	--	--	--	***0.00013***
Cu, tot.	mg/L	--	--	--	--	--	--
Cu, ext.	mg/L	--	--	--	--	--	***0.00035***
Fe, tot.	mg/L	--	--	--	--	--	--
Fe, ext.	mg/L	--	0.02	--	--	--	0.087
Li, ext.	mg/L	--	--	--	--	--	***0.031***
Pb, tot.	mg/L	--	--	--	--	--	--
Pb, ext.	mg/L	--	--	--	--	--	***0.00014***
Mn, tot.	mg/L	--	--	--	--	--	--
Mn, ext.	mg/L	--	--	--	--	--	0.043
Hg, tot.	ug/L	--	--	--	--	--	--
Mo, tot.	mg/L	--	--	--	--	--	--
Mo, ext.	mg/L	--	--	--	--	--	***0.00058***
Ni, tot.	mg/L	--	--	--	--	--	--
Ni, ext.	mg/L	--	--	--	--	--	***0.00032***
Sb, ext.	mg/L	--	--	--	--	--	***0.00011***
Se, tot.	mg/L	--	--	--	--	--	--
Se, ext.	mg/L	--	--	--	--	--	***<0.0005***
Sn, ext.	mg/L	--	--	--	--	--	***<0.0001***
Sr, ext.	mg/L	--	--	--	--	--	***0.3***
Th, ext.	mg/L	--	--	--	--	--	***0.000005***
Ti, ext.	mg/L	--	--	--	--	--	***0.001***
Tl, ext.	mg/L	--	--	--	--	--	***<0.000003***
U, ext.	mg/L	--	--	--	--	--	***0.00079***
Va, tot.	mg/L	--	--	--	--	--	--
Va, ext.	mg/L	--	--	--	--	--	***0.00049***
Zn, tot.	mg/L	--	--	--	--	--	--
Zn, ext.	mg/L	--	--	--	--	--	***0.00127***

Notes:

[a] hyphens indicate that a variable was not measured

bold/italics = one sample only

VARIABLE	UNITS	GHOSTPINE CREEK AT HWY 585 NEAR TROCHU			GHOSTPINE CREEK AT HWY 27		
		86	99	00	86	99	00
	No. Samples:	4	6	5	4	11	6
TP-ARCV	mg/L	--	0.315	0.485	--	0.253	0.471
TP-Maxxam	mg/L	0.495	--	--	0.420	--	--
TDP-ARCV	mg/L	--	0.203	0.333	--	0.206	0.406
TDP-Maxxam	mg/L	--	--	--	--	--	--
PO_4, diss. Ortho	mg/L	0.385	--	--	0.293	--	--
P, part.	mg/L	--	0.048	0.057	--	0.042	0.065
TKN	mg/L	2.03	2.00	2.12	2.07	1.83	2.33
NH_3, tot.	mg/L	0.090	--	--	0.055	--	--
NH_3, diss.	mg/L	--	0.034	0.026	--	0.022	0.025
NO_2+NO_3-N, diss.	mg/L	0.015	0.006	0.006	0.026	0.003	0.008
Nitrite, diss.	mg/L	--	--	--	--	--	--
TN	mg/L	--	--	--	--	--	--
N, part.	mg/L	--	--	--	--	--	--
Silica	mg/L	10.3	--	--	4.3	--	--
TOC	mg/L	22.0	--	--	23.7	--	--
TIC	mg/L	94.0	--	--	82.3	--	--
DOC	mg/L	--	--	--	--	--	--
DIC	mg/L	--	--	--	--	--	--
C, part.	mg/L	--	--	--	--	--	--
COD	mg/L	70	--	--	73	--	--
CHL *a*	mg/m3	--	3.9	4.8	--	7.4	10.2
Phenols	mg/L	0.016	--	--	0.011	--	--
Dissolved Oxygen	mg/L	5.7	11.4	11.1	8.6	10.2	9.9
Water Temp	deg C	16.00	10.53	19.34	16.00	15.67	16.64
Air Temp	deg C	--	--	22.0	--	--	17.0
Colour, True	TCU	200	--	--	250	--	--
Conductance	uS/cm	1415	1139	1540	1305	1354	1645
TDS, calc.	mg/L	--	--	--	--	--	--
TDS	mg/L	--	--	--	--	--	--
NFR	mg/L	15	--	8	30	--	7
FR	mg/L	891	--	--	838	--	--
Total Residue	mg/L	--	--	--	--	--	--
Turbidity	NTU	19.00	--	8.30	40.00	--	9.10

VARIABLE	UNITS	GHOSTPINE CREEK AT HWY 585 NEAR TROCHU			GHOSTPINE CREEK AT HWY 27		
		86	99	00	86	99	00
No. Samples:		4	6	5	4	11	6
Total Alkalinity	mg/L	455	--	--	395	--	--
PP Alkalinity	mg/L	5.2	--	--	7.0	--	--
pH	units	8.28	8.44	8.67	8.27	8.62	8.86
Hardness	mg/L	252	--	--	221	--	--
Sodium, diss.	mg/L	231	--	--	208	--	--
Calcium, diss.	mg/L	37.5	--	--	35.6	--	--
Magnesium, diss.	mg/L	38.4	--	--	32.0	--	--
Potassium, diss.	mg/L	9.8	--	--	9.3	--	--
Chloride, diss.	mg/L	8.5	--	--	7.1	--	--
Chlorine, ext.	mg/L	--	--	--	--	--	--
Sulphate, diss.	mg/L	297	--	--	293	--	--
Sulphide, diss.	mg/L	--	--	--	--	--	--
Fluoride, diss.	mg/L	0.21	--	--	0.23	-- --	
Bicarbonate	mg/L	541	--	--	464	--	--
Carbonate, diss.	mg/L	6	--	--	9	--	--
Odour	TON	--	--	--	--	--	0.5
Secchi Depth	m	--	--	--	--	--	--
Total Coliforms	no./dL	35	--	--	405	--	--
Fecal Coliforms	no./dL	20	--	--	50	--	--
Escherichia Coli	no./dL	--	--	--	--	--	--
Ag, ext.	mg/L	--	--	--	--	--	--
Al, tot.	mg/L	--	--	--	--	--	--
Al, ext.	mg/L	--	--	0.188	--	--	0.260
As, tot.	mg/L	--	--	--	--	--	--
As, diss.	mg/L	--	--	--	--	--	--
As, ext.	mg/L	--	--	--	--	--	--
B, ext.	mg/L	--	--	--	--	--	--
Ba, tot.	mg/L	--	--	--	--	--	--
Ba, ext.	mg/L	--	--	--	--	--	--
Be, tot.	mg/L	--	--	--	--	--	--
Be, diss.	mg/L	--	--	--	--	--	--
Be, ext.	mg/L	--	--	--	--	--	--
Bi, ext.	mg/L	--	--	--	--	--	--
Cd, tot.	mg/L	--	--	--	--	--	--

VARIABLE	UNITS	GHOSTPINE CREEK AT HWY 585 NEAR TROCHU			GHOSTPINE CREEK AT HWY 27		
		86	99	00	86	99	00
No. Samples:		4	6	5	4	11	6
Cd, ext.	mg/L	--	--	--	--	--	--
Cr, tot.	mg/L	--	--	--	--	--	--
Cr, ext.	mg/L	--	--	--	--	--	--
Co, tot.	mg/L	--	--	--	--	--	--
Co, ext.	mg/L	--	--	--	--	--	--
Cu, tot.	mg/L	--	--	--	--	--	--
Cu, ext.	mg/L	--	--	--	--	--	--
Fe, tot.	mg/L	--	--	--	--	--	--
Fe, ext.	mg/L	0.22	--	0.32	0.61	--	0.244
Li, ext.	mg/L	--	--	--	--	--	--
Pb, tot.	mg/L	--	--	--	--	--	--
Pb, ext.	mg/L	--	--	--	--	--	--
Mn, tot.	mg/L	--	--	--	--	--	--
Mn, ext.	mg/L	--	--	0.051	--	--	0.047
Hg, tot.	ug/L	--	--	--	--	--	--
Mo, tot.	mg/L	--	--	--	--	--	--
Mo, ext.	mg/L	--	--	--	--	--	--
Ni, tot.	mg/L	--	--	--	--	--	--
Ni, ext.	mg/L	--	--	--	--	--	--
Sb, ext.	mg/L	--	--	--	--	--	--
Se, tot.	mg/L	--	--	--	--	--	--
Se, ext.	mg/L	--	--	--	--	--	--
Sn, ext.	mg/L	--	--	--	--	--	--
Sr, ext.	mg/L	--	--	--	--	--	--
Th, ext.	mg/L	--	--	--	--	--	--
Ti, ext.	mg/L	--	--	--	--	--	--
Tl, ext.	mg/L	--	--	--	--	--	--
U, ext.	mg/L	--	--	--	--	--	--
Va, tot.	mg/L	--	--	--	--	--	--
Va, ext.	mg/L	--	--	--	--	--	--
Zn, tot.	mg/L	--	--	--	--	--	--
Zn, ext.	mg/L	--	--	--	--	--	--

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bold/italics = one sample only

VARIABLE	UNITS	GHOSTPINE CREEK AT HWY 585 NEAR TROCHU 86	99	00	GHOSTPINE CREEK AT HWY 27 86	99	00
	No. Samples:	4	6	5	4	11	6
Total Alkalinity	mg/L	455	--	--	395	--	--
PP Alkalinity	mg/L	5.2	--	--	7.0	--	--
pH	units	8.28	8.44	8.67	8.27	8.62	8.86
Hardness	mg/L	252	--	--	221	--	--
Sodium, diss.	mg/L	231	--	--	208	--	--
Calcium, diss.	mg/L	37.5	--	--	35.6	--	--
Magnesium, diss.	mg/L	38.4	--	--	32.0	--	--
Potassium, diss.	mg/L	9.8	--	--	9.3	--	--
Chloride, diss.	mg/L	8.5	--	--	7.1	--	--
Chlorine, ext.	mg/L	--	--	--	--	--	--
Sulphate, diss.	mg/L	297	--	--	293	--	--
Sulphide, diss.	mg/L	--	--	--	--	--	--
Fluoride, diss.	mg/L	0.21	--	--	0.23	-- --	
Bicarbonate	mg/L	541	--	--	464	--	--
Carbonate, diss.	mg/L	6	--	--	9	--	--
Odour	TON	--	--	--	--	--	0.5
Secchi Depth	m	--	--	--	--	--	--
Total Coliforms	no./dL	35	--	--	405	--	--
Fecal Coliforms	no./dL	20	--	--	50	--	--
Escherichia Coli	no./dL	--	--	--	--	--	--
Ag, ext.	mg/L	--	--	--	--	--	--
Al, tot.	mg/L	--	--	--	--	--	--
Al, ext.	mg/L	--	--	0.188	--	--	0.260
As, tot.	mg/L	--	--	--	--	--	--
As, diss.	mg/L	--	--	--	--	--	--
As, ext.	mg/L	--	--	--	--	--	--
B, ext.	mg/L	--	--	--	--	--	--
Ba, tot.	mg/L	--	--	--	--	--	--
Ba, ext.	mg/L	--	--	--	--	--	--
Be, tot.	mg/L	--	--	--	--	--	--
Be, diss.	mg/L	--	--	--	--	--	--
Be, ext.	mg/L	--	--	--	--	--	--
Bi, ext.	mg/L	--	--	--	--	--	--
Cd, tot.	mg/L	--	--	--	--	--	--

VARIABLE	UNITS	GHOSTPINE CREEK AT HWY 585 NEAR TROCHU			GHOSTPINE CREEK AT HWY 27		
		86	99	00	86	99	00
	No. Samples:	4	6	5	4	11	6
Cd, ext.	mg/L	--	--	--	--	--	--
Cr, tot.	mg/L	--	--	--	--	--	--
Cr, ext.	mg/L	--	--	--	--	--	--
Co, tot.	mg/L	--	--	--	--	--	--
Co, ext.	mg/L	--	--	--	--	--	--
Cu, tot.	mg/L	--	--	--	--	--	--
Cu, ext.	mg/L	--	--	--	--	--	--
Fe, tot.	mg/L	--	--	--	--	--	--
Fe, ext.	mg/L	0.22	--	0.32	0.61	--	0.244
Li, ext.	mg/L	--	--	--	--	--	--
Pb, tot.	mg/L	--	--	--	--	--	--
Pb, ext.	mg/L	--	--	--	--	--	--
Mn, tot.	mg/L	--	--	--	--	--	--
Mn, ext.	mg/L	--	--	0.051	--	--	0.047
Hg, tot.	ug/L	--	--	--	--	--	--
Mo, tot.	mg/L	--	--	--	--	--	--
Mo, ext.	mg/L	--	--	--	--	--	--
Ni, tot.	mg/L	--	--	--	--	--	--
Ni, ext.	mg/L	--	--	--	--	--	--
Sb, ext.	mg/L	--	--	--	--	--	--
Se, tot.	mg/L	--	--	--	--	--	--
Se, ext.	mg/L	--	--	--	--	--	--
Sn, ext.	mg/L	--	--	--	--	--	--
Sr, ext.	mg/L	--	--	--	--	--	--
Th, ext.	mg/L	--	--	--	--	--	--
Ti, ext.	mg/L	--	--	--	--	--	--
Tl, ext.	mg/L	--	--	--	--	--	--
U, ext.	mg/L	--	--	--	--	--	--
Va, tot.	mg/L	--	--	--	--	--	--
Va, ext.	mg/L	--	--	--	--	--	--
Zn, tot.	mg/L	--	--	--	--	--	--
Zn, ext.	mg/L	--	--	--	--	--	--

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